Interpretation of an Aeromagnetic Survey of the Amchitka Island Area, Alaska

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GEOLOGICAL SURVEY PROFESSIONAL PAPER 707

Prepared on behalf of the
U.S. Atomic Energy Commission

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1972

UNITED STATES DEPARTMENT OF THE INTERIOR

ROGERS C. B. MORTON, Secretary

GEOLOGICAL SURVEY

V. E. McKelvey, Director

Library of Congress catalog-card No. 70-189816

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402
Stock Number 2401-2087

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INTERPRETATION OF AN AEROMAGNETIC SURVEY OF THE AMCHITKA ISLAND AREA, ALASKA

By G. D. BATH, W. J. CARR, L. M. GARD, JR., and W. D. QUINLIVAN

ABSTRACT

An aeromagnetic survey of about 1,800 square miles of Amchitka Island and the adjacent insular shelf has provided information on Tertiary volcanic, intrusive, and sedimentary rocks. This includes identification of rocks that cause anomalies and the lateral extents, structures, and approximate depths of those rocks. Near proposed drill sites, anomalies were examined for features that might be related to faulting. The survey was facilitated by data on the magnetic properties of 347 rock specimens collected from surface exposures and 216 from drill cores and by plots of 25 miles of ground magnetic traverse. The data on magnetic properties furnished bases on which anomalies were related to geologic features; ground surveys classified near-surface rocks as either lava or breccia.

The total magnetization of volcanic breccia, tuff breccia, volcanic sandstone, and siltstone averages about 7.0×10^{-4} gauss, an effective direction generally being along the earth's magnetic field. This value is designated as the "ambient magnetization level" for the area. The prominent anomalies come directly from lava flows and thick sills that have total magnetizations which differ from the ambient level for the island. Anomalies also come indirectly from large bodies of intrusive rock that have altered and destroyed the magnetite content of overlying flow rocks. The average for 219 surface and 81 core specimens of lava is 14.2×10^{-4} gauss induced intensity and 12.8×10^{-4} gauss remanent intensity. Lavas of the Chitka Point Formation have normal remanent polarities and produce positive anomalies. The basalt lavas of the Banjo Point Formation, as well as the pillow lavas and breccias of Kirilof Point in the upper part of the Amchitka Formation, have both normal and intermediate polarities and produce positive and negative anomalies. Individual breccia samples from the Banjo Point Formation and the lower part of the Amchitka Formation have significant values of remanent intensity, but directions vary so greatly from sample to sample that a thick section of breccia does not give a magnetic anomaly. Although dikes and small sills have total magnetizations well above the ambient level, their thicknesses are too small to give a significant effect at the datum plane 1,600 feet above sea level. The normal polarity of the White House Cove intrusive and the reversed polarity of the East Cape intrusive confirm that these intrusives are separate features, emplaced at different geologic times.

Computation of the effects of sheetlike models shows that the steeper gradients of theoretical anomalies are positioned near the ends of flows or sills that have been terminated by faulting. Drill sites were selected in areas away from gradients considered to be fault related.

Nearly all prominent anomalies over land and many over water can be reasonably interpreted and can be correlated with known geologic features. Anomalies and geologic data suggest that the magma of the Chitka Point Formation originated in a large volcanic center on western Amchitka Island and eastern Rat Island. Faults that are well delineated by aeromagnetic contours on Amchitka do not appear to extend very far seaward, and marked submarine trenches that have the same general trend are not well defined magnetically.

INTRODUCTION

An aeromagnetic survey of Amchitka and Rat Islands and the adjacent insular shelf was made during December 1966 and January 1967 to gain information on the structure and subsurface distribution of Tertiary extrusive and intrusive rocks. An area of about 1,800 square miles was covered by the aeromagnetic survey. The resulting data were supplemented by laboratory data on the magnetic properties of 347 rock specimens collected from surface exposures and of 216 from drill cores and by plots of 25 miles of ground magnetic traverse.

The main purpose of the study was to investigate anomalies near proposed drill sites (fig. 1; see also pl. 2), particularly emphasizing the recognition of features that might be related to faulting and the detection of large intrusive bodies at depth. Major faults may control the initial deposition or emplacement of magnetized rock or may displace rock boundaries and their associated magnetic anomalies. Anomalies in random pattern seldom indicate structure, but those that have dominant or drawn-out trends or abrupt terminations suggest a relation to faulting.

To identify near-surface rock sources, positions of anomalies were compared with geologic units as mapped by Carr and Quinlivan (1969). The magnetic properties of surface and drill-core rock samples were investigated to determine whether the geologic units possessed magnetic properties that could cause anomalies.

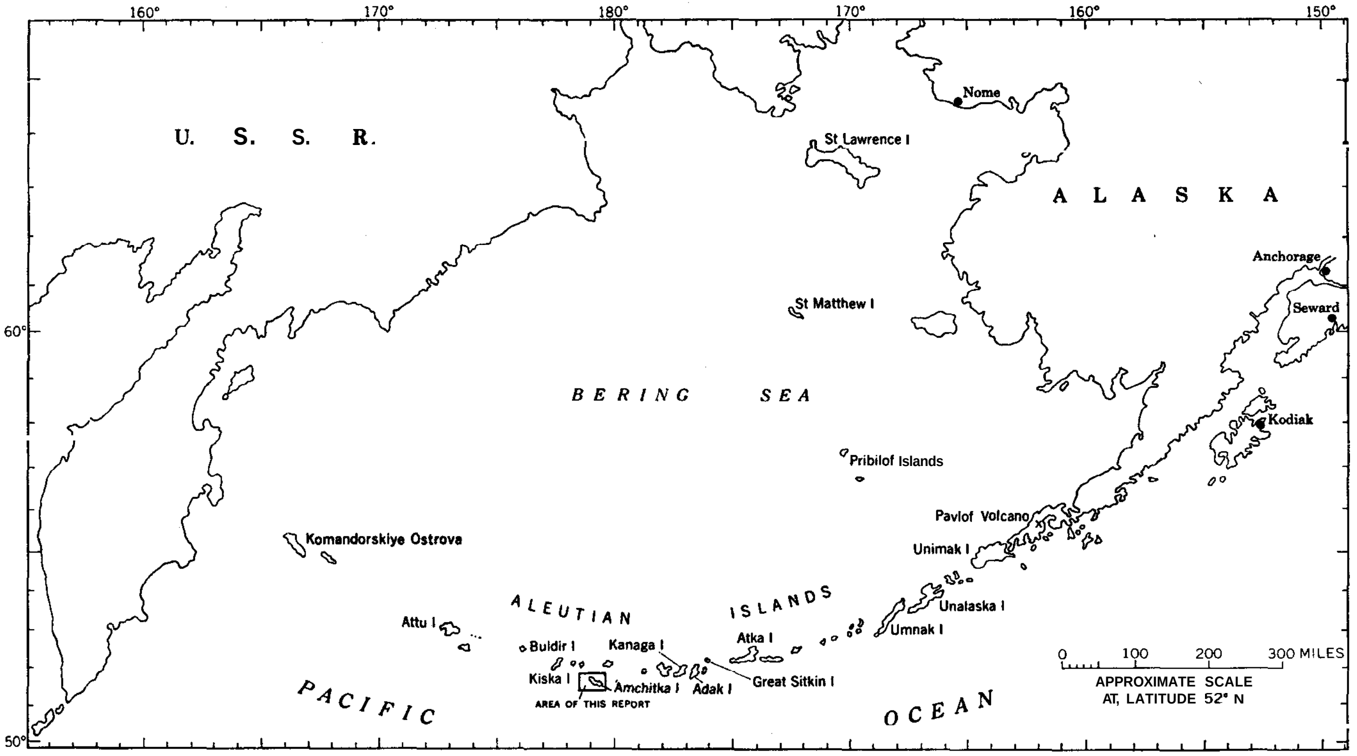

FIGURE 1. — Index map of Amchitka Island and the Aleutian arc.

PREVIOUS MAGNETIC SURVEYS

One of the most exciting investigations in recent years surrounded the discovery by Mason (1958) that the floor of the Pacific Ocean produces remarkably regular magnetic anomalies, or magnetic lineations, which form parallel patterns, often extending for distances of several hundred miles. Since then, studies by numerous investigators have resulted in the discovery of similar anomalies in the Atlantic and Indian Oceans and in the development of comprehensive new theories that make use of the concepts of paleornagnetism (Cox and others, **1964**), sea-floor spreading (Vine, **1966**), and continental drift (**LePichon,** 1968) to explain the geologic history of oceanic areas.

Hayes and Heirtzler (1968) discussed the relation of magnetic lineations south of Amchitka, beyond the Aleutian trench, to the Aleutian Islands arc and trench. Abrupt changes in continuity of the anomalies south of the trench suggest large north-south displacements or faults in the sea floor that offset anomaly patterns as much as 150 miles. The limited data now available from shipborne surveys do not indicate that any displacements trend toward Amchitka Island. Grim and Erickson (1968) inferred a small north-south offset in the magnetic pattern near long **177°** W., 175 miles east of Amchitka, which they called the Adak fracture zone. Hayes and Heirtzler inferred a large north-south fracture zone at long **176°** E., 100 miles west of Amchitka.

No anomaly lineations have been reported over the oceans north of the Aleutian trench, and neither the magnetic anomalies nor the magnetic properties at Amchitka resemble those from ocean areas. In a study of 94 submarine lava samples, Ade-Hall (1964) found that 67.5 percent of the samples had magnetic susceptibilities less than 10×10^{-4} gauss per oersted and that 61 had Koenigsberger ratios greater than 10. On Amchitka, less than 10 percent of the andesitic and basaltic lavas (see histograms, figs. 9, 10) had susceptibilities less than 10×10^{-4} gauss per oersted or **Koenigsberger** ratios greater than 10. Although basaltic lavas do show high Koenigsberger ratios, their susceptibilities are also high, averaging about 40×10^{-4} gauss per oersted.

Keller, Meuschke, and Alldredge (1954) published aeromagnetic survey data for northern Adak Island, part of Umnak Island, and Great Sitkin Island. Magnetic properties are unknown for the volcanic formations on these islands, and the anomalies cannot be discussed in terms of geologic features. The fairly large number of positive anomalies suggests the presence of normally magnetized lava, such as the Chitka Point lavas on Amchitka. Richards, Vacquier, and Van Voorhis (1967) computed the direction and intensity of magnetism for the Quaternary volcanic rocks that form the topographic relief of Great Sitkin volcano on Great Sitkin Island, and of Mount Adagdak, Mount Moffett, and a parasitic cone on the northeastern side of Mount Moffett on Adak Island. Directions of magnetization for the four volcanoes are quite different, a fact indicating that the anomaly-producing rocks are products of separate eruptive episodes.

AEROMAGNETIC SURVEY

As shown on the aeromagnetic map (pl. 1), more than 65 flight lines were flown: 12 long lines and a few short lines were flown northwest and southeast at about a ½-mile spacing along the axis of the island, and 51 long lines were flown northeast and southwest at about a 1-mile spacing; two tielines were flown in the northwest direction, one over the north insular slope and one over the south insular slope. A barometric elevation of about 1,600 feet was maintained throughout the survey by means of a continuously recording radio altimeter. The magnetic measurements were made by a continuously recording Gulf fluxgate magnetometer, installed in a DC–3 aircraft equipped with loran and Doppler navigational systems. Aero Service Corp. performed the aerial survey and compiled the data shown on plate 1.

REDUCTION OF DATA

The observed data consist of both residual and regional magnetic anomalies. The residual anomalies are of particular interest because they come from geologic features that are near surface or buried only a mile or two. The regional anomaly is not important in this study because it comes from the northward increase in the geomagnetic field and from rock sources too deep to investigate by drilling. A least-squares method (Richards and others, 1967) was used to eliminate the regional anomaly or, that not being possible, to reduce its contribution to a minimum in the small area of the survey.

On the assumption that a planar surface would best fit the data and represent the regional anomaly to be discarded, the observed data of plate 1 were plotted on a rectangular grid representing a length of 50 miles in the x direction (S. 55° E. along the island axis) and a width of 30 miles in the y direction. Based on 1,500 data samples taken at 1-mile grid intervals, the least-squares adjustment, arrived at by means of an electronic computer, provided the following equation for the regional anomaly:

$$T(x,y)=C_1x+C_2y+C_3.$$

$T(x,y)$ is the regional anomaly, in gammas, computed for coordinates x, y; C_1 equals 1.70 gammas per mile, C_2 equals −9.64 gammas per mile, and C_3 equals 4,304.6 gammas at lat 51'54.6' N. and long 178°56.0′ E.

The residual anomaly, which is the near-surface magnetic expression of a geologic feature, was graphically determined by subtracting data on the regional anomaly from the observed data. The 50-gamma contours of plate 2 show detailed residual anomalies for most of the area of the survey at a scale of 1:100,000.

GROUND MAGNETIC SURVEYS

Ground magnetic surveys, taken along roads, were conducted to determine if there are significant differences in anomaly patterns over volcanic breccia and over basaltic lava flows. The ground surveys also served to provide the detail needed to better delineate the aeromagnetic anomalies. Plate 3 shows the residual magnetic anomaly and standard error data obtained from stations 0.1 mile apart along Infantry Road from mile 0 on Kirilof Point to mile 23 northwest of drill hole UAe–3, along Clevenger Road, and along the access road to drill hole UAe–1. At each station, five readings were taken 5 feet apart, and the values were averaged to give the magnetic anomaly at that station. Anomaly-producing rocks are close to the surface beneath the tundra, and the proximity of strongly magnetized rock introduces extreme local anomalies. A measure of these effects is shown by computing the standard error of the five readings and plotting the error as a bar, as done in the lower diagram, "Standard Error, In Gammas," plate 3.

The Sharpe MF–1 fluxgate magnetometer used in the survey provided values of the vertical component of the earth's magnetic field. Owing to the effects of temperature changes and other factors, readings could only be repeated to within ±20 gammas. Four base stations were established, and one base was reoccupied about every 3 hours to correct for large changes in the earth's diurnal field.

MAGNETIC PROPERTIES OF ROCK SAMPLES

A magnetic survey detects those geologic features that have magnetic properties unusual enough to cause a disturbance, or an anomaly, in the earth's magnetic field. The anomaly arises when a feature has a total magnetization that is significantly different from the total magnetization of the surrounding rocks.

The average total magnetization of a uniformly magnetized rock mass, denoted as the vector J_t, is defined as the vector sum of the induced magnetization, J_i, and remanent magnetization, J_r, of the mass:

$$J_t = J_i + J_r. \quad (1)$$

The direction of induced magnetization is assumed along the earth's field, and the intensity of induced magnetization is a function of the magnetic susceptibility, k, and the strength, H_o, of the earth's field:

$$J_i = kH_o. \quad (2)$$

The direction and intensity of the earth's magnetic field are known for Amchitka (explanation, pl. 1) ; therefore, it is magnetic susceptibility, direction, and intensity of remanent magnetization that must be measured to evaluate total magnetization. For this study, the dry bulk density of each sample was measured to provide an independent parameter that could help in determining whether or not the selected rock samples were representative.

Histograms give magnetic properties and densities for 563 rock specimens collected from surface outcrops and drill cores (figs. 2–4, 6, 9, 10). Numbers and types of rock specimens used were: 85 surface and 74 drill-core specimens of volcanic breccia; 61 drill-core specimens of volcanic sandstone, siltstone, and tuff breccia; 43 surface specimens of intrusive rock; and 219 surface and 81 drill-core specimens of andesitic and basaltic flows, sills, and dikes. Koenigsberger ratios (the ratios of remanent to induced intensities of rock samples J_r/J_i), are also included as a histogram. Site locations for the surface samples are shown on plate 2.

In reporting units of magnetic intensity, the authors followed Collinson, Creer, and Runcorn (1967) in their attempt to specify electromagnetic units more precisely. Magnetic susceptibility is expressed in gauss per oersted, and induced, remanent, and total intensities are expressed in gauss.

The extreme scatter found in magnetic property data indicates that the usual procedure of using an arithmetic mean places too much emphasis on large values and yields an average value that is greater than the true total magnetization of a geologic feature. Statistical studies by Irving, Molyneux, and Runcorn (1966) suggest that histograms of magnetic properties may conform more closely to a normal distribution when the abscissas are plotted as logarithms. Our studies, though incomplete, tend to confirm their conclusions, and the histograms included in this report were therefore plotted with logarithmic abscissas.

The reader will note the use of the words "sample," "specimen," and "sampling site." Rock samples were collected from points separated by at least 50 feet. Specimens were taken closer together vertically, coming from the same core run of 10-foot length, or from two or three pieces drilled from the same surface sample. Sampling sites were as much as 1 mile apart.

MEASURING MAGNETIC SUSCEPTIBILITY

Reversible magnetic susceptibilities were determined by inserting samples into one of a pair of matched Helmholtz coils connected to an induction comparison bridge. For large roughhewn samples, coils whose inside diameter is 8¼ inches were used; and for small, 1-inch diameter by 1-inch length drilled plugs, coils whose inside diameter is 2½ inches were used. Meter deflections were calibrated against a commercially available alternating-current bridge by using a set of standard samples.

MEASURING REMANENT MAGNETIZATION

The intensity, azimuth, and inclination of remanent magnetization were determined for both large roughhewn and small drilled plugs by means of a commercially available fluxgate-type clip-on milliammeter, modified to function as a magnetometer. Jahren and Bath (1967) described the procedure that the present authors used.

Surface samples were oriented before they were removed from the outcrop by marking a north arrow on the sample top and a horizontal line on two or more sides. An arrow pointing upward was marked on all pieces of drill core immediately after the core was taken from the core barrel. Although the geographic azimuth is unknown, the intensity and inclination of remanent magnetization were obtained for cores from vertical holes. Most of the samples collected during the geological reconnaissance were not oriented; however, the remanent intensity was determined for many of them.

At the Nevada Test Site (Bath, 1967), lightning introduces a relatively strong component of remanent magnetism that is confined to near-surface rocks. Tabulation of data from these samples will not give a true value of average magnetism for a geologic feature under study. In Nevada, data were used from underground samples that were free from these effects and from surface samples in which remanent direction remained constant during partial alternating-field demagnetization in the laboratory. Although lightning has rarely been observed on Amchitka, the possibility of contamination effects cannot be ignored, because parts of the island have been above sea level for perhaps 1 million years (Powers and others, 1960). The present authors partially demagnetized 24 surface and seven drill-core samples of andesitic and basaltic lava in alternating-current fields of 100 and 200 oersteds and found no significant directional changes in the moderately to strongly magnetized rocks that produce the aeromagnetic anomalies. Some of the weakly magnetized rocks did show changes in their remanent directions. This change is explained as being the result of a component of viscous magnetization or the remanent effect acquired when a rock remains in the earth's magnetic field over a long period of time. In this study, it has been assumed that lightning has not introduced a significant error in the magnetization values.

GEOLOGIC SETTING

The stratigraphy and structure of Amchitka are now fairly well known as the result of recent studies by Carr and Quinlivan (1969) and earlier work by Powers, Coats, and Nelson (1960). As shown on the generalized geologic map (pl. 2), the rocks are divided into (1) the Amchitka Formation, which comprises a lower unit of older breccias and an upper unit of the pillow lavas and breccias of Kirilof Point, (2) the Banjo Point Formation, and (3) the Chitka Point Formation.

The lower Tertiary Amchitka Formation is the oldest formation exposed on the island. Rocks in the northwestern part of Amchitka formerly mapped as Amchitka Formation are now included in the Chitka Point Formation (Carr and others, 1970), and rocks on eastern Amchitka are included either in the older breccias or in the pillow lavas and breccias of Kirilof Point.

The outcrops of older breccias of the Amchitka Formation are restricted to the eastern part of Amchitka, mainly between Constantine Harbor and the quartz diorite intrusive rocks of East Cape. Inliers of hornfels occur within the intrusive masses. The unit consists of fine- to coarse-grained sedimentary breccias and lavas with poorly developed pillows interbedded with small amounts of sandstone, siltstone, and claystone which contain volcanic debris. Most of the rocks are propylitically altered. The degree of alteration increases erratically eastward toward the intrusive complex, and strongly metamorphosed older breccias occur adjacent to the intrusive masses. The upper contact of the older breccias is placed at the base of a locally glassy lava sequence and at the top of a thin interval of sedimentary rocks. Numerous dikes, many of hornblende andesite, cut the breccias on the eastern part of Amchitka. More than 3,000 feet of the older breccias is exposed, but because of the thickness of numerous dikes and sills that intrude the section and the possibility of fault repetition, this value indicates a maximum thickness.

The pillow lavas and breccias of Kirilof Point consist of glassy monolithologic breccias and subordinate pillow lava flows and a lesser amount of bedded volcanic sedimentary rocks. All these were probably deposited in a submarine environment. Compositionally, the rocks of Kirilof Point are less mafic than others known on Amchitka; Powers, Coats, and Nelson (1960) published an analysis of hydrated glassy breccia from Kirilof Point which indicates that the rock is a latite. The Kirilof Point rocks are about 3,500 feet thick in the vicinity of Pillow Point.

The Banjo Point Formation overlies the Amchitka Formation, showing only a slight unconformity, and is composed mainly of basaltic breccias, a few pillow lavas, and volcaniclastic sedimentary rocks, all of submarine deposition. Hornblende andesite and basalt sills are present locally. Because of a major erosional unconformity at the top, no complete section of the Banjo Point is exposed. The formation is probably between 2,000 and 5,000 feet thick and is late Eocene or Oligocene in age (Carr and others, 1970).

The Chitka Point Formation overlies the Banjo Point Formation with marked unconformity and is restricted (Carr and others, 1970) to subaerial hornblende andesite and pyroxene andesite lava flows, breccias, tuffs, and conglomerate in the northwestern part of Amchitka (pl. 2). Included in the Chitka Point Formation by the present authors are all rocks previously mapped by Powers, Coats, and Nelson (1960) as Amchitka Formation on the northwestern part of the island and some rocks in small areas along the Bering Sea coast (between about lat 51°30′ N. and Cyril Cove), previously mapped as Banjo Point Formation. The Chitka Point ranges in thickness from 0 near the middle of Amchitka to at least 2,000 feet in the vicinity of Top Side in northwestern Amchitka. On the basis of a potassium-argon date and other evidence, the Chitka Point Formation is determined to be Miocene (Carr and others, 1970).

Dioritic intrusive rocks cut the Chitka Point Formation on the western part of Amchitka and the older breccias of the Amchitka Formation on the eastern part of the island. Intense hydrothermal al-

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teration of the Chitka Point Formation in the Chitka Cove area may be related to the diorite that crops out at White House Cove (pl. 2). Much of the Chitka Point Formation and the older breccias of the Amchitka Formation are affected by weak to strong propylitic alteration, producing epidote, quartz, calcite, chlorite, and pyrite. In addition to causing locally intense alteration, the intrusives gently tilt the invaded rocks at White House Cove and on the eastern part of Amchitka east of St. Makarius Point.

Although faults are not as abundant as aerial photograph lineaments suggest, there are perhaps a dozen major fault zones, a few of which may have a width of several thousand feet and within which the rocks may be highly fractured. Most of the major faults trend about N. 70° E. and dip northwest at 75°–90°. Although some of the movement appears to be lateral, some faults have stratigraphic displacement of as much as 4,000 ft. The middle third of the island is a series of fault blocks that repeat the southeastward-dipping section. Most of the major faulting predates the Chitka Point Formation.

Within the area of the aeromagnetic survey are three important submarine fault systems. One lies 5–10 km (kilometers) (3–6 miles) north of Amchitka and Rat Islands along a prominent escarpment. In addition to outlining the escarpment, faults of this system border the basins and ridges between Amchitka and Semisopochnoi Islands. Most of these structural features appear to be younger than the Chitka Point Formation. Southeast of Amchitka about 40 km (25 miles), on the slopes descending into Amchitka Canyon and Ward Basin, are east-northeast-trending faults that parallel those on Amchitka and probably have the same general sense of displacement. About 25 km (15 miles) south of Amchitka on the insular slope are several sharply incised asymmetric submarine canyons. These mark northeast-trending faults, downthrown on the northwest. These faults cannot be connected with certainty to any exposed on Amchitka.

VOLCANIC BRECCIA

Breccias are an important part of the entire stratigraphic section on Amchitka; most of the samples were collected from the Banjo Point Formation. L. M. Gard and W. E. Hale (unpub. data, 1964) showed that the Banjo Point consists of a thick series of submarine basaltic breccias, lapilli tuffs, and conglomerates, and a small number of intercalated beds of volcanic sandstone, siltstone, shale, and tuff.

MAGNETIC PROPERTIES

The volcanic breccia consists mostly of coarse fragments of volcanic material that was rapidly deposited at low temperature by submarine landslides. During deposition, the earth's magnetic field alines the smaller magnetized fragments so that they settle to the ocean bottom in a consistent direction of remanent magnetization. If this alinement is maintained throughout consolidation and cementation, a deposit consisting mainly of small fragments will acquire a bulk magnetization that is directed along the earth's magnetic field. The earth's field could not, however, affect larger pieces of magnetized material, especially those deposited rapidly. These larger pieces, therefore, would give the breccia a random remanent magnetization.

Experiments with breccia core runs of the Banjo Point from exploratory drill hole UAe–1 verify that the remanent directions are basically random. Measurements on 15 core pieces from core run 1 (Gard and others, 1969), oriented with arrows pointing upward, gave seven upward or negative inclinations, six downward or positive inclinations, and two nearly horizontal inclinations. Inclinations for the 14 pieces of breccia from core run 2 were: seven negative, five positive, and two horizontal. Other breccia core pieces gave similar results.

The present authors concluded that this wide scatter effect of disoriented breccia fragments on remanent magnetization will cancel most of the remanent contribution to the total magnetization of a large breccia deposit. Equation 1 then reduces to $J_t \approx J_i$.

The histograms of figure 2 present data from 97 breccia specimens, all the breccia measured to date. Logarithmic averages are 14.8×10^{-4} gauss per oersted for magnetic susceptibility, 5.1×10^{-4} gauss for remanent intensity, and 0.72 for Koenigsberger ratio. The average density is 2.36 g/cc (grams per cubic centimeter). Equations 2 and 3 (p. 4, 11) determine that the total magnetization becomes 7.1×10^{-4} gauss in the direction of the earth's magnetic field. Because breccia is the predominant lithology of Amchitka, the authors have designated this total magnetism of breccia as the ambient level for the island. A large geologic structure having a magnetization that differs in intensity or direction from the ambient level should, therefore, produce a residual magnetic anomaly.

The 41 core samples from the Long Shot drill hole EH–5, collected at depths from 76 to 1,999 feet, are considered to be representative of breccia of the Banjo Point Formation. Data from these samples have the following averages: Dry bulk density, 2.36 **g/cc**; magnetic susceptibility, **19.8×10^{-4}** gauss per oersted; remanent intensity, **16.0×10^{-4}** gauss; and total intensity, **9.5×10^{-4}** gauss in the direction of the earth's magnetic field. The relatively high **remanence** of these pieces of core is apparently caused by a few large breccia fragments and is not the remanence of the rock as a whole.

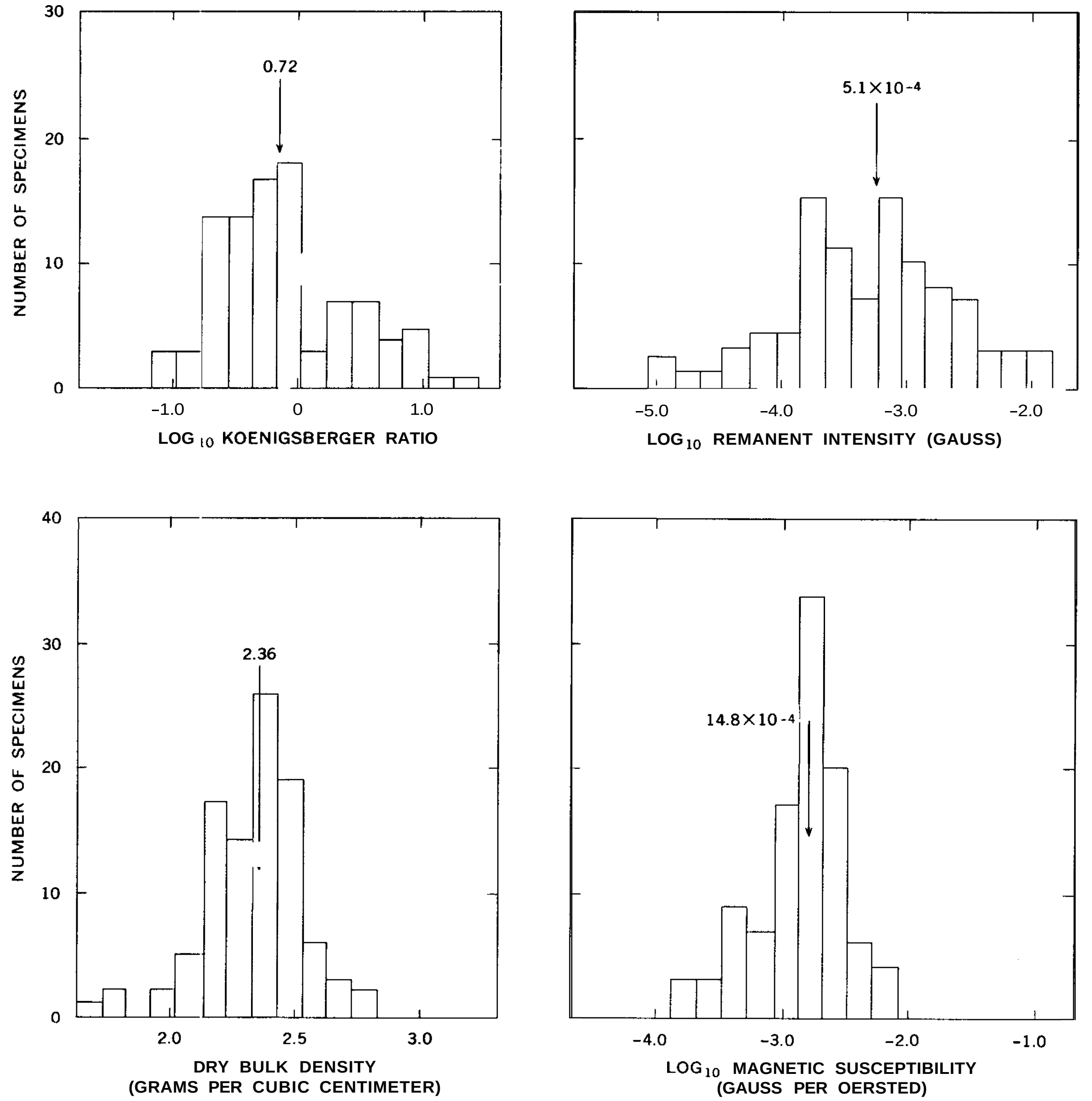

FIGURE 2. — Histograms of Koenigsberger ratio, density, remanent intensity, and magnetic susceptibility for 97 specimens of volcanic breccia. Arrow indicates average value.

Histograms (fig. 3) list properties for 62 lithic fragments removed from two surface samples of the breccia of the Banjo Point Formation. Most of the pieces are from lava flows that were probably originally **emplaced** away from the present island area.

Core sections of the breccia of Kirilof Point and the underlying older breccias from UAe-1 have rather different average total magnetizations. Thirteen samples of breccia of Kirilof Point from depths of 2,415–4,925 feet gave averages of 2.32 **g/cc** for density, **4.9×10^{-4} gauss** per oersted for magnetic susceptibility, **5.1×10^{-4}** gauss for remanent intensity, and **2.4×10^{-4}** gauss for total intensity. Thirteen samples of older breccia from depths of 5,756–6,997 feet gave averages of 2.45 **g/cc** for density, **33.9×10^{-4}** gauss per oersted for magnetic susceptibility, **5.9×10^{-4}** gauss for remanent intensity, and **16.2×10^{-4}** gauss for total intensity.

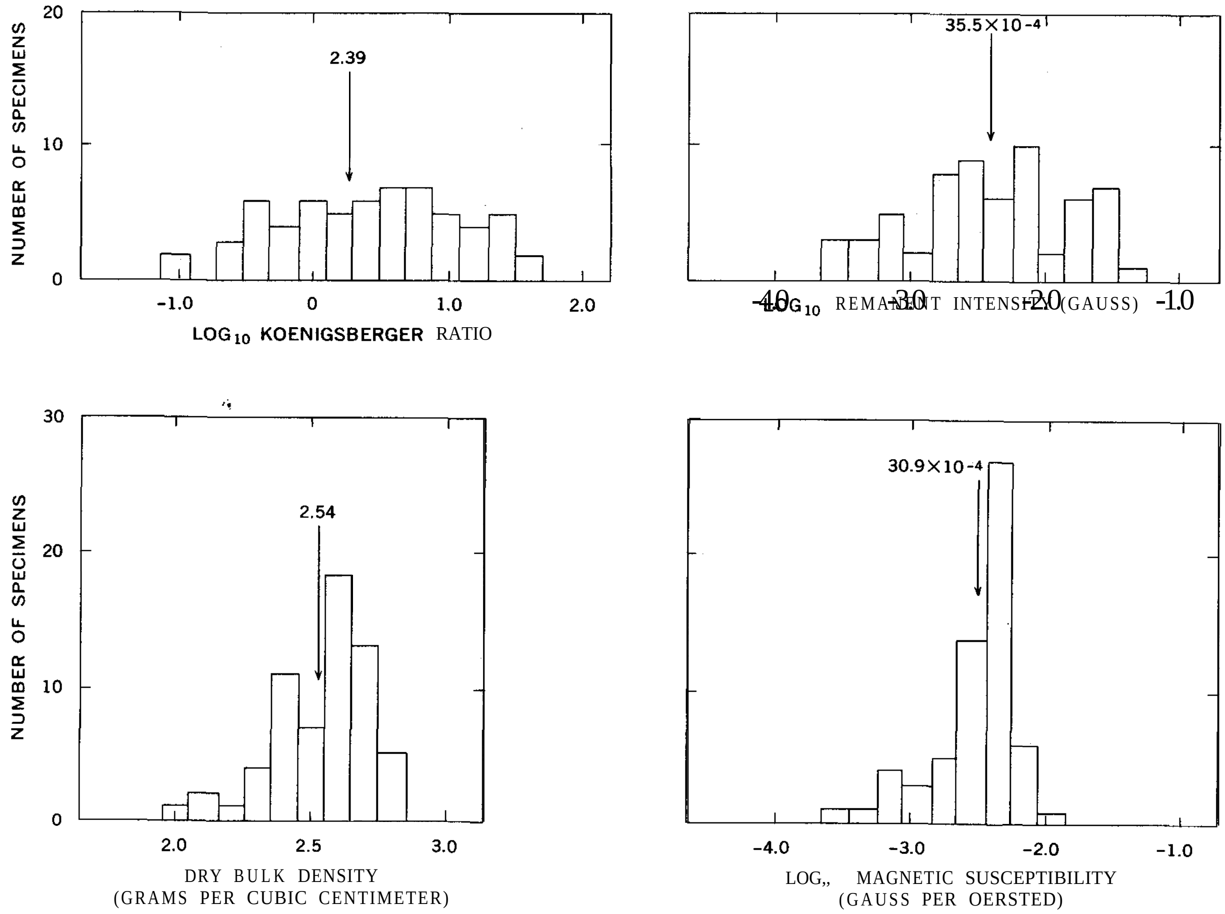

FIGURE 3. — **Histograms of Koenigsberger ratio, density, remanent intensity, and magnetic susceptibility for 62 specimens of volcanic breccia fragments. Arrow indicates average value.**

AEROMAGNETIC ANOMALIES

Aeromagnetic traverses over the large area of Banjo Point breccias and the older breccias (pl. 2) show an anomaly level that is generally above the regional value but is interrupted by several prominent and many local negative and positive anomalies. In the area of the Banjo Point Formation, the marked negative anomalies have been named "Mex Island," "—780," and "Rifle Range Point" anomalies. The most marked positive effect is named the "Site B" anomaly. As will be pointed out in a following section, the marked positive and negative anomalies come from lava flows or sills and do not represent the magnetic effect of breccia. The magnetic field becomes fairly uniform after lava-related anomalies are removed.

GROUND SURVEY ANOMALIES

A striking difference in average anomaly amplitude and standard error is present over breccia and lava flows. The magnetic expressions of the breccia are relatively uniform and have lower values than the lavas, except that the contrast is not great between the Chitka Point lava flows and the Banjo Point breccias. In the Infantry Road traverse (pl. 3), the 8½ miles over the Banjo Point Formation (from mile 8 to mile 16.5) and the 6½ miles over the Chitka Point Formation (from mile 16.5 to mile 23) averaged less than 1,000 gammas for anomaly amplitude and less than 50 gammas for standard error. Low values of standard error come from near-surface breccia; high values.from small near-surface features such as flows, dikes, or sills.

From mile 0 to mile 5, the pillow lavas and breccias of Kirilof Point as mapped by Carr and Quinlivan (1969) show extreme magnetic effects. Anomaly amplitudes reach values of 5,000 gammas and show standard errors of 600 gammas over near-surface and strongly magnetized lava flows. From the data of plate 3 the following near-surface source rocks may be identified: lava from mile 0 to mile 0.7, breccia from 0.8 to 1.1, mostly lava from 1.2 to 2.1, mostly breccia from 2.2 to 3.0, and mostly lava from 3.1 to 4.

The short traverse along the access road to drill hole UAe–1 presents an excellent example of the characteristic low values of standard error that are found over near-surface breccia. The traverse also locates the Mex Island anomaly more accurately than the aeromagnetic survey does. The ground data of plate 3 place the anomaly minimum at 0.3 mile from UAe–1, not at 0.6 mile as indicated by the aeromagnetic data (pl. 2).

VOLCANIC SANDSTONE, SILTSTONE, AND TUFF BRECCIA

Although Carr and Quinlivan (1969) reported interbedded sedimentary rocks in the Chitka Point and Banjo Point Formations and in the older breccias of the Amchitka Formation, the beds are too thin to be mapped at the 1:100,000 scale, and the outcrop areas are too small to be correlated with individual aeromagnetic anomalies. Sedimentary rocks may be more extensive in some areas offshore as suggested by the abrupt change of the character of the magnetic field (pl. 1) in the area of the broad positive anomaly about 10 miles north of Chitka Point. A thick deposit of rocks having consonant total magnetizations is required to explain the uniform nature of the field.

The histograms of figure 4 present data from 30 core specimens of volcanic sandstone and siltstone and 31 specimens of tuff breccia, collected at depths ranging from 543 to 2,225 feet in drill hole EH–5. Logarithmic averages are 11.0×10^{-4} gauss per oersted for magnetic susceptibility, 1.4×10^{-4} gauss for remanent intensity, and 0.26 for Koenigsberger ratio.

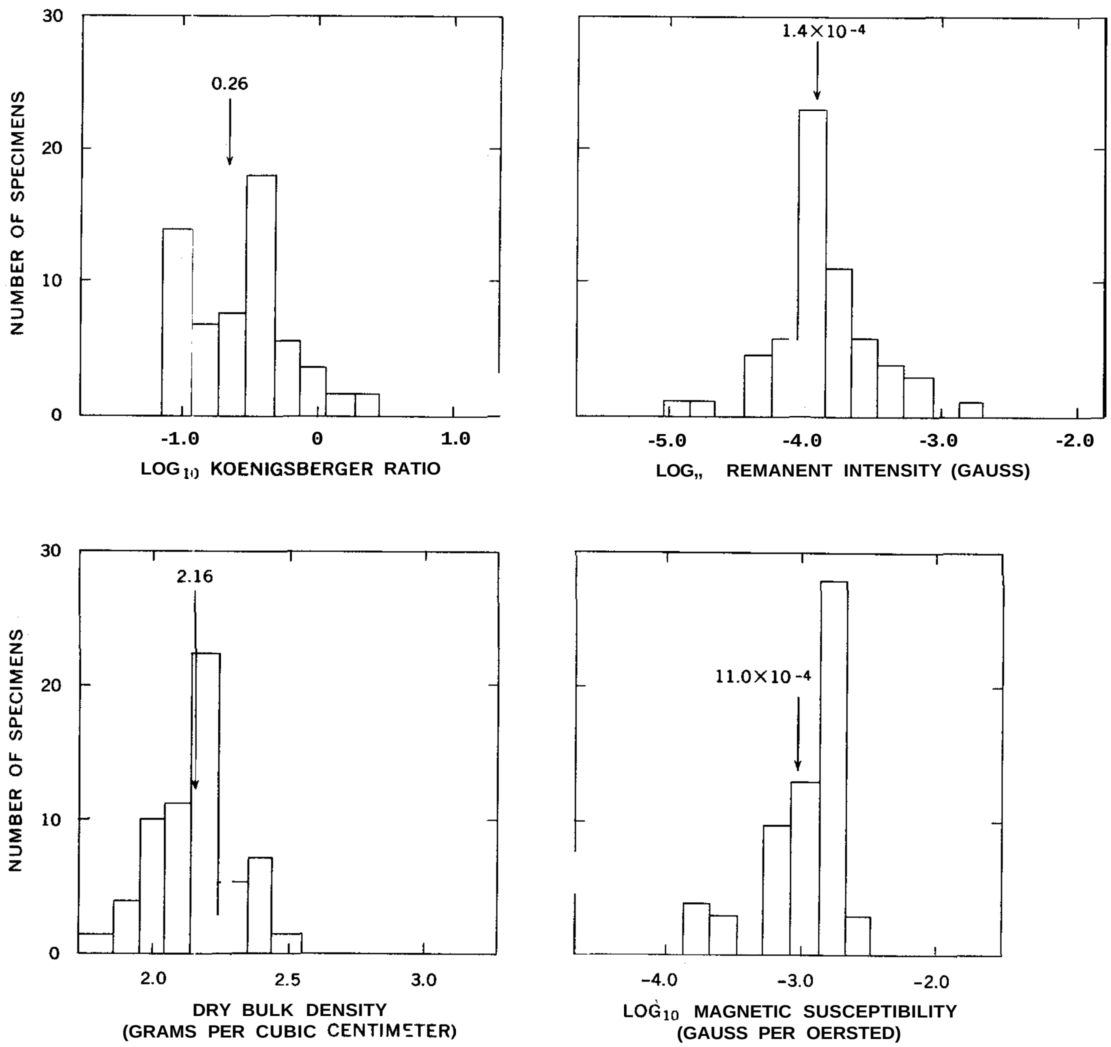

FIGURE 4. — Histograms of Koenigsberger ratio, density, remanent intensity, and magnetic susceptibility for 61 specimens of volcanic sandstone, siltstone, and tuff breccia from drill hole EH–5. Arrow indicates average value.

The average density is 2.16 g/cc. Except for remanent direction, average values are similar for the volcanic sandstone and siltstone and the tuff breccia.

The authors assumed no structural tilting and obtained true values of remanent inclinations by measurement of drill cores that were referenced to a vertical drill hole. Remanent azimuths are unknown, but a measurement of variation was obtained by referencing azimuth to a line marked along seven continuous lengths of drill core before these lengths were cut into several specimens. Figure 5 gives inclinations and variations in azimuth for drill-core Samples collected from EH–5. The low average inclination of 27" for 16 specimens of volcanic sandstone and siltstone is difficult to explain. One possible explanation is the tendency of platy magnetic particles to settle horizontally and thus be only partially alined by the earth's magnetic field. Most of these samples are from graded beds or fine-grained, rapidly deposited sediments. For 17 specimens of tuff breccia, the average inclination is **67°**, or close to the **62°** value for the geomagnetic field, a condition which suggests the effect of a viscous magnetization acquired after emplacement.

The total magnetization of volcanic sandstone, siltstone, and tuff breccia is controlled by magnetic susceptibility, or induced magnetism. The low Koenigsberger ratio of 0.26 shows that the contribution of remanent magnetism is relatively unimportant. The authors therefore assign these fine-grained sedimentary rocks an average total magnetization of 6.5×10^{-4} gauss in the direction of the geomagnetic field.

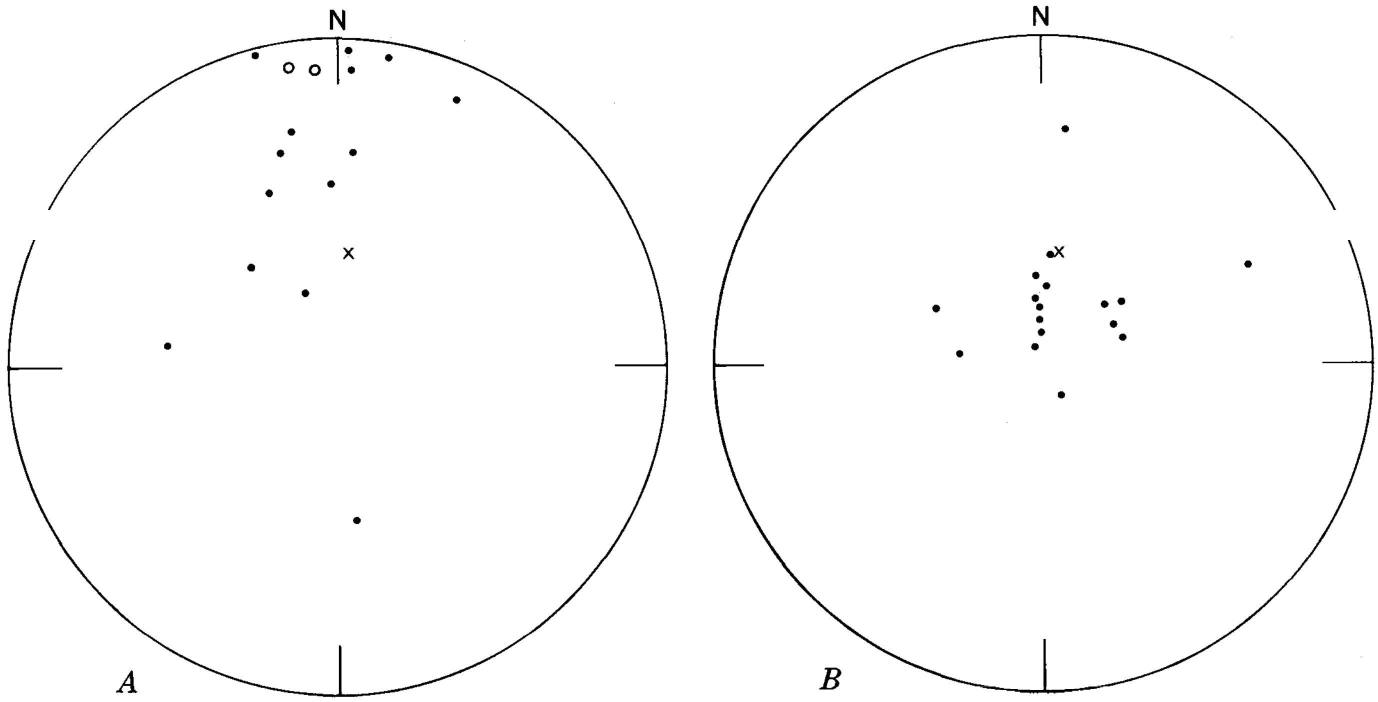

FIGURE 5. — Equal-area projections of remanent directions of magnetization for specimens cut from continuous lengths of core from drill hole EH–5: A, 16 specimens of volcanic sandstone and siltstone; B, 17 specimens of tuff breccia. Differences in azimuth are referenced to an arbitrary line marked along the core before it was cut. The average of all azimuths is assumed northward, but inclinations are referenced to a vertical drill hole and are, therefore, true values. ●, lower hemisphere; O, upper hemisphere; ×, present geomagnetic field.

DIKES AND SMALL SILLS

The presence of dikes and sills beneath prominent aeromagnetic anomalies suggests that the magnetic contribution of several of these small features is sufficient to explain some of the anomalies. For example, the —780 and St. Makarius Point anomalies shown on plate 2 are over complexes of basaltic dikes and small sills intruded into the Banjo Point Formation. Most of the dikes and sills exposed in these areas have thicknesses that are less than 50 feet. From the geologic detail shown by Carr and Quinlivan **(1969)**, it seems clear that these features should be considered as possible source rocks. The St. Makarius Point and —780 anomalies are discussed in more detail under the section on "Interpretation of Anomalies."

Data are available for 30 surface samples collected from dikes and small sills (pl. 2). Logarithmic averages are 25.7×10^{-4} gauss per oersted for magnetic susceptibility, 5.5×10^{-4} gauss for remanent intensity, and 0.45 for Koenigsberger ratio. A maximum value of 17.8×10^{-4} gauss for total magnetization is computed from these data. Subtracting the ambient level value (7.0×10^{-4}) from 17.8×10^{-4} gauss, the effective total magnetization for the 30 samples collected from dikes and small sills becomes 10.8×10^{-4} gauss. A single dike or small sill that has this value of effective total magnetization will produce an aeromagnetic anomaly of little importance at the datum plane 1,600 feet above sea level. Assuming a thickness, ε, of 50 feet and a depth, t, of 1,200 feet, computations using the equation

$$\Delta T_{max} = \frac{2J_t\,\varepsilon\,10^5}{t} \text{ gammas} \qquad (3)$$

give a maximum anomaly, ΔT_{max}, of only 9 gammas for a total magnetization, J_t, of 10.8×10^{-4} gauss. Computation for a sill 50 feet thick at a depth of 1,200 feet,

$$\Delta T_{max} = \frac{2.4J_t\,\varepsilon\,10^5}{t} \text{ gammas,} \qquad (4)$$

gives a maximum anomaly of only 11 gammas (fig. 15). Because the effect of a single dike is small, the authors have concluded that a complex of many dikes is required to explain a prominent aeromagnetic anomaly.

INTRUSIVE ROCKS

Samples of intrusive rock were collected from the complex of diorites and andesites exposed on the eastern part of the island, from exposures on White House Cove, Chapel Cove, and Ivakin Point, and from intrusive features that are too small to be shown on plate 2.

MAGNETIC PROPERTIES

The histograms of figure 6 present data from 43 specimens of intrusive rock. Logarithmic averages are 12.5×10^{-4} gauss per oersted for magnetic susceptibility, 5.1×10^{-4} gauss for remanent intensity, and 0.85 for Koenigsberger ratio. The average density is 2.55 g/cc. The broad spectrum of values shown in the remanent intensity histogram indicates the presence of more than one pluton. A closer inspection of the data reveals that the lower values come from the complex exposed on the eastern part of the island, including Ivakin Point. Table 1 shows an average remanent intensity of 1.3×10^{-4} gauss for eight specimens from the East Cape pluton and 19.7×10^{-4} gauss for 16 specimens from the White House Cove intrusive.

TABLE 1. — *Average of densities and magnetic properties for eight specimens collected from the East Cape pluton and 16 specimens collected from the White House Cove intrusive*

	East Cape pluton	White House Cove intrusive
Density ... g/cc..	2.58	2.50
Magnetic susceptibility ... $\times10^{-4}$ gauss per oersted..	11.9	20.8
Induced intensity ... $\times10^{-4}$ gauss..	5.7	10.0
Induced direction:		
Declination ... degrees..	7	7
Inclination ... do .	62	62
Remanent intensity ... $\times10^{-4}$ gauss..	1.3	19.7
Remanent direction :		
Declination ... degrees	181	5
Inclination ... do	75	69
Total intensity ... $\times10^{-4}$ gauss..	6.6	29.6
Total direction:		
Declination ... degrees.	8	6
Inclination ... do..	69	66

Difference in directions of remanent magnetism supports the concept of two separate episodes of intrusion. Experts in paleomagnetic investigations of remanent directions now generally agree that, during cooling and crystallization, the magnetic minerals in igneous rocks become magnetized in the direction of the earth's magnetic field. In the geologic past, the earth's magnetic field has changed direction and has undergone numerous complete reversals of polarity (Cox and others, 1964). Directions for 16 specimens collected from the White House Cove intrusive (fig. 7) have a normal polarity that averages 5° in declination and 69° in inclination, a direction that approximates the 7° declination and 62° inclination of the present geomagnetic field on Amchitka. Partial demagnetization of three of the specimens in alternating fields of 100 and 200 oersteds did not result in a significant change in direction, and the natural-state magnetism appears to be stable and related to the direction of an ancient geomagnetic field.

In marked contrast, the remanent data of figure 8 from eight specimens of the East Cape pluton show an intermediate polarity, having an average declination of 181° and an inclination of 75°. The natural-state magnetism contains an unstable component of viscous remanent magnetization which was removed by partial demagnetization. At 100 oersteds (table 2), inclination changed from plus to minus. The average direction for three specimens at 200 oersteds gives a reversed polarity, or a declination of 188° and an inclination of −49°.

Table 1 gives the total magnetization values that are used in the interpretive studies of the two plutons. The reader may be surprised to find that even though the direction of fossil remanent magnetization for the East Cape pluton is reversed, the average direction of total magnetization, shown in figure 8, is normal and approximates the earth's present magnetic field. This is the result of the low 0.23 value of Koenigsberger ratio. The remanent effect becomes trivial when it is added vectorially to the induced effect.

AEROMAGNETIC ANOMALIES

The positions of several aeromagnetic anomalies that have values well below the regional level correlate with the positions of large exposures of intrusive rock. The East Cape negative anomaly is over a complex of diorites on the eastern end of the island (pl. 2). The White House Cove negative anomalies are over exposures of intrusive rock at White House and Chapel Coves. A less pronounced low occurs near the intrusive complex at Ivakin Point.

LAVA FLOWS AND THICK SILLS

Lava flows and thick sills produce most of the pronounced aeromagnetic anomalies. Of particular importance are the thick andesite lava flows of the Chitka Point Formation, the andesitic and basaltic lavas within the Banjo Point Formation, and the latitic pillow lavas of Kirilof Point in the Amchitka Formation.

TABLE 2. — *Average remanent directions and intensities for three specimens collected from the East Cape pluton, measured at natural state and after partial alternating field demagnetization to 100 and 200 oersteds*

[Collected at sample site 13, pl. 21

	Natural state	Demagnetization level	
		100 oersted	200 oersted
Specimen B25A1–67:			
Declination........degrees..	189	199	203
Inclination........do.	44	—49	—58
Intensity........1 0 gauss..	3.8	3.0	2.9
Specimen B25A2–67:			
Declination........deg..	169	187	184
Inclination........do.	66	−46	−46
Intensity........$\times 10^{-4}$ gauss..	1.5	.7	.7
Specimen B25C1–67:			
Declination........deg..	128	170	178
Inclination........do..	72	−40	−46
Intensity........$\times 10^{-4}$ gauss..	17	.4	.3

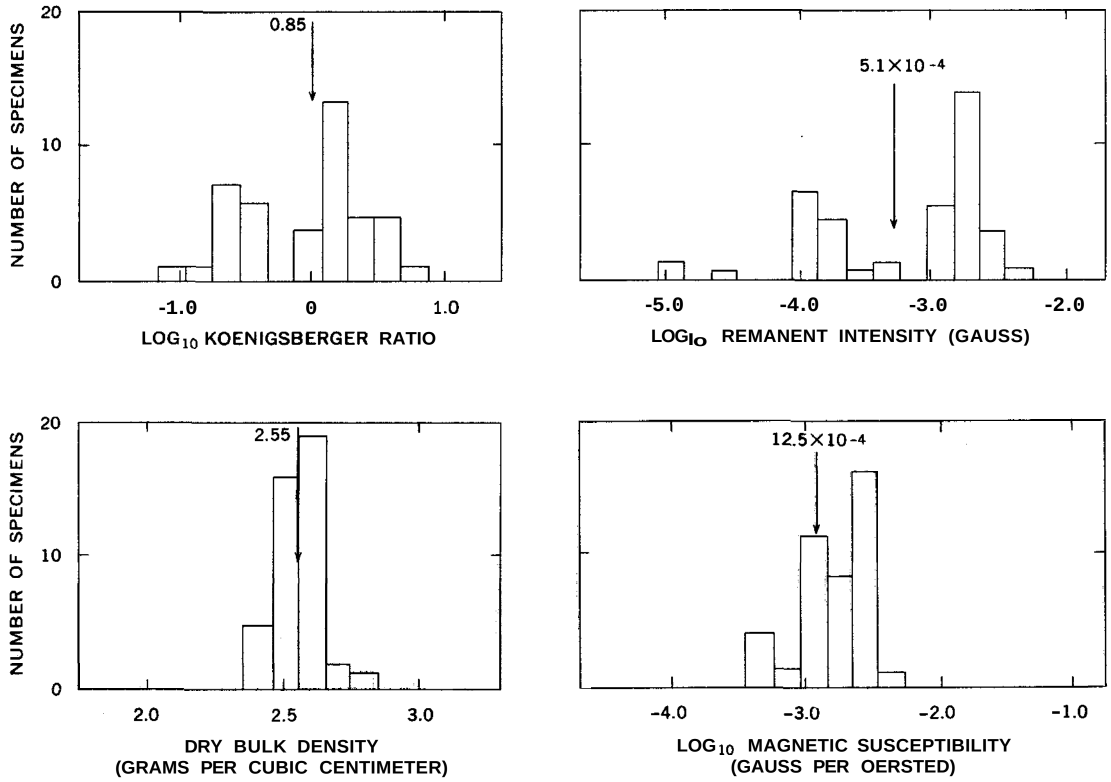

FIGURE 6. — Histograms of Koenigsberger ratio, density, remanent intensity, and magnetic susceptibility for 43 specimens of intrusive rock. Arrow indicates average value.

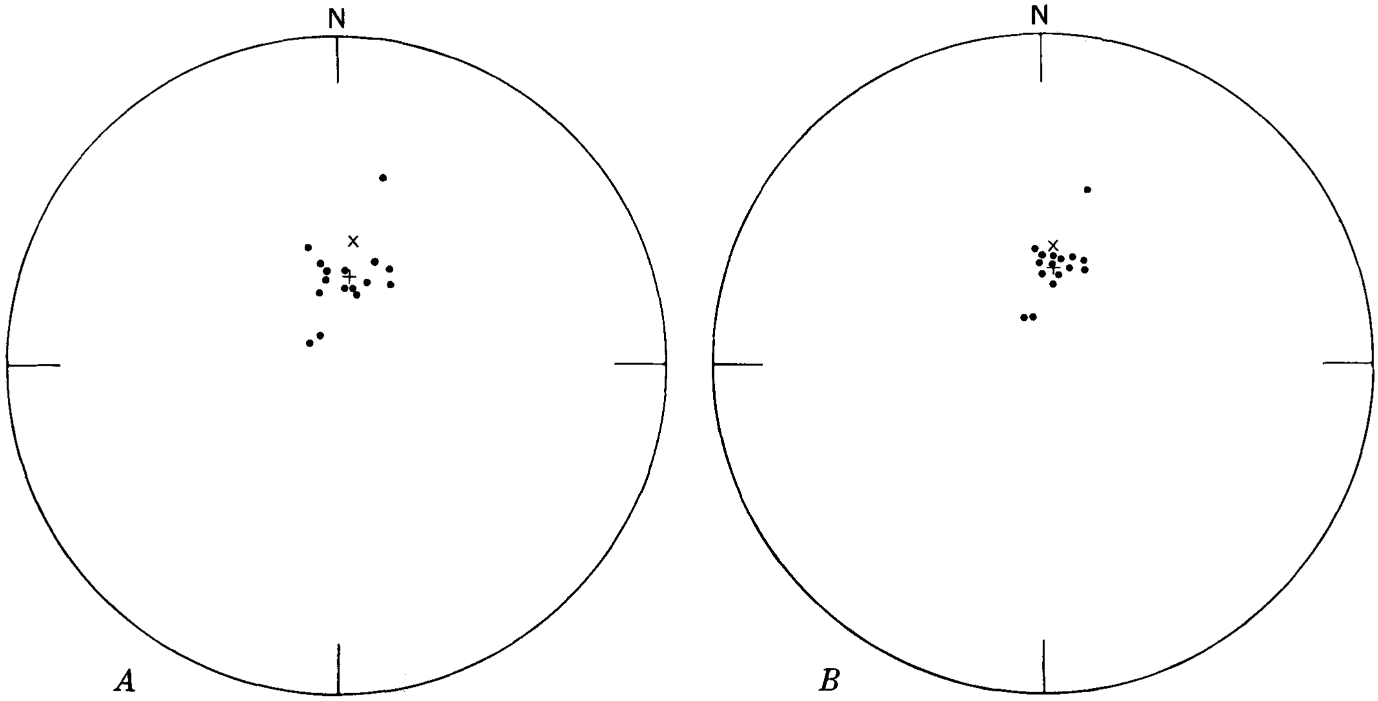

FIGURE 7. — Equal-area projections of remanent (A) and total (B) directions of magnetization for 16 specimens of intrusive rock collected from surface exposures of the White House Cove intrusive. ●, lower hemisphere; ×, present geomagnetic field; +, average direction.

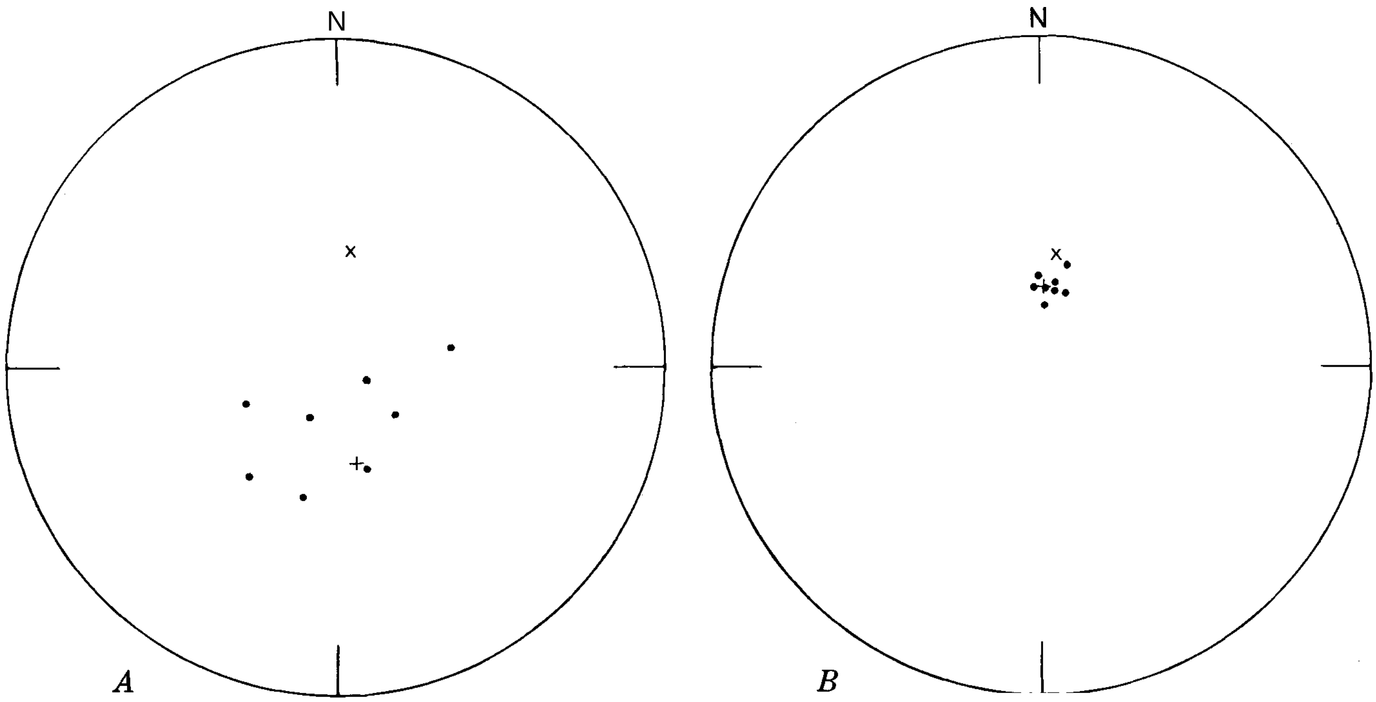

FIGURE 8. — Equal-area projections of remanent (A) and total (B) directions of magnetization for 8 specimens of intrusive rock collected from surface exposures of the East Cape pluton. ●, lower hemisphere; ×, present geomagnetic field; +, average direction.

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MAGNETIC PROPERTIES

The histograms of figures 9 and 10 present data from 219 surface and 81 drill-core specimens of lava flows, sills, and dikes. The surface samples (fig. 9) were collected from all areas of the island except the areas of undivided intrusive rocks (pl. 2). Their logarithmic averages are 22.9×10^{-4} gauss per oersted for magnetic susceptibility, 9.8×10^{-4} gauss for remanent intensity, and 0.89 for Koenigsberger ratio. The average density is 2.6 g/cc. The subsurface data (fig. 10) were taken from the following: 30 specimens from drill hole EH–5, 12 from UAe–1, 24 from UAe–2, 10 from UAe–3, and five from UAe–7c. Their logarithmic averages are 36.3×10^{-4} gauss per oersted for magnetic susceptibility, 15.9×10^{-4} gauss for remanent intensity, and 0.91 for Koenigsberger ratio. The average density is 2.49 g/cc.

Although remanent directions at Amchitka appear generally constant throughout individual flows or sills, average directions may change from formation to formation, and even within some formations. For example, all pieces of the pillow lavas of Kirilof Point from core runs 4, 5, 6, 16, and 18 of UAe–1 (Gard and others, 1969) have negative inclinations that average about −60°. The change from formation to formation is demonstrated by the data from

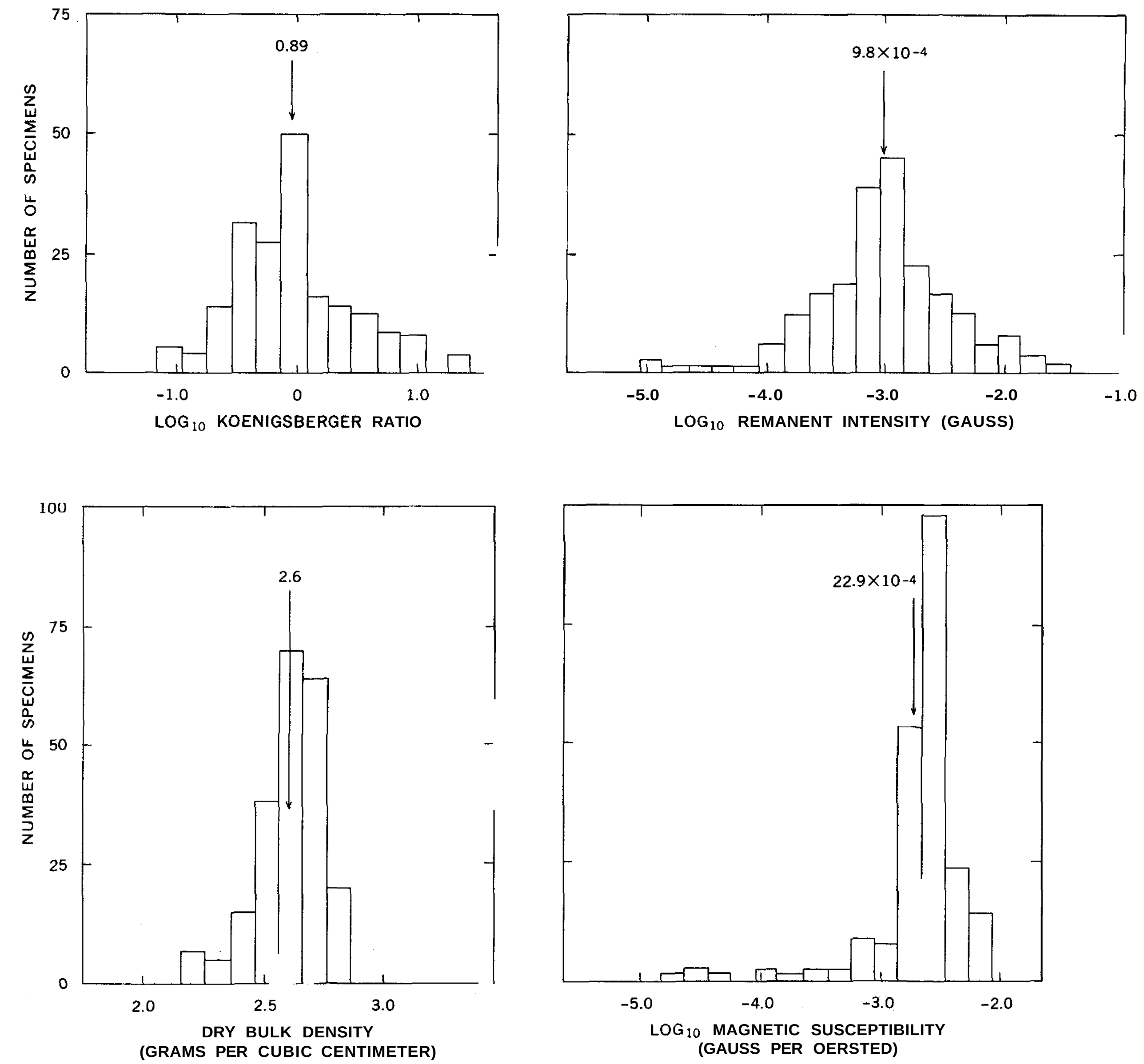

FIGURE 9.—Histograms of Koenigsberger ratio, density, remanent intensity, and magnetic susceptibility for 219 surface specimens of andesitic and basaltic flows, sills, and dikes. Arrow indicates average value.

drill hole **UAe–2,** located about 5 miles southeast of **UAe–1.** Four core samples of lava collected from the Banjo Point Formation at depths of **2,578–3,103** feet have positive rather than negative inclinations that average **68°.** However, not **all** units in the Banjo Point have the same magnetic characteristics, as illustrated by the negative inclinations of lava samples at depths of 2,227–2,244 feet in drill hole EH–5.

Small changes in remanent inclination can be interpreted in a similar manner. Inclinations of andesite core from EH–5 have the following averages and 95-percent confidence intervals: **76°±6°** for seven samples from 2,340.8- to 2,342.2-foot depth; **55°±11°** for eight samples from 2,466- to **2,468.3**-foot depth; and **41°±4°** for five samples from **2,479.7**- to 2,480.9-foot depth. The **76°** average differs significantly from the 55" and 41" averages, and the authors thus assume that the andesite at the more shallow depth was **emplaced** at a different time.

The remanent data plotted in figure **11** indicate that the thick lava flows of the Chitka Point Formation have normal polarities. The 58 surface **speci-**

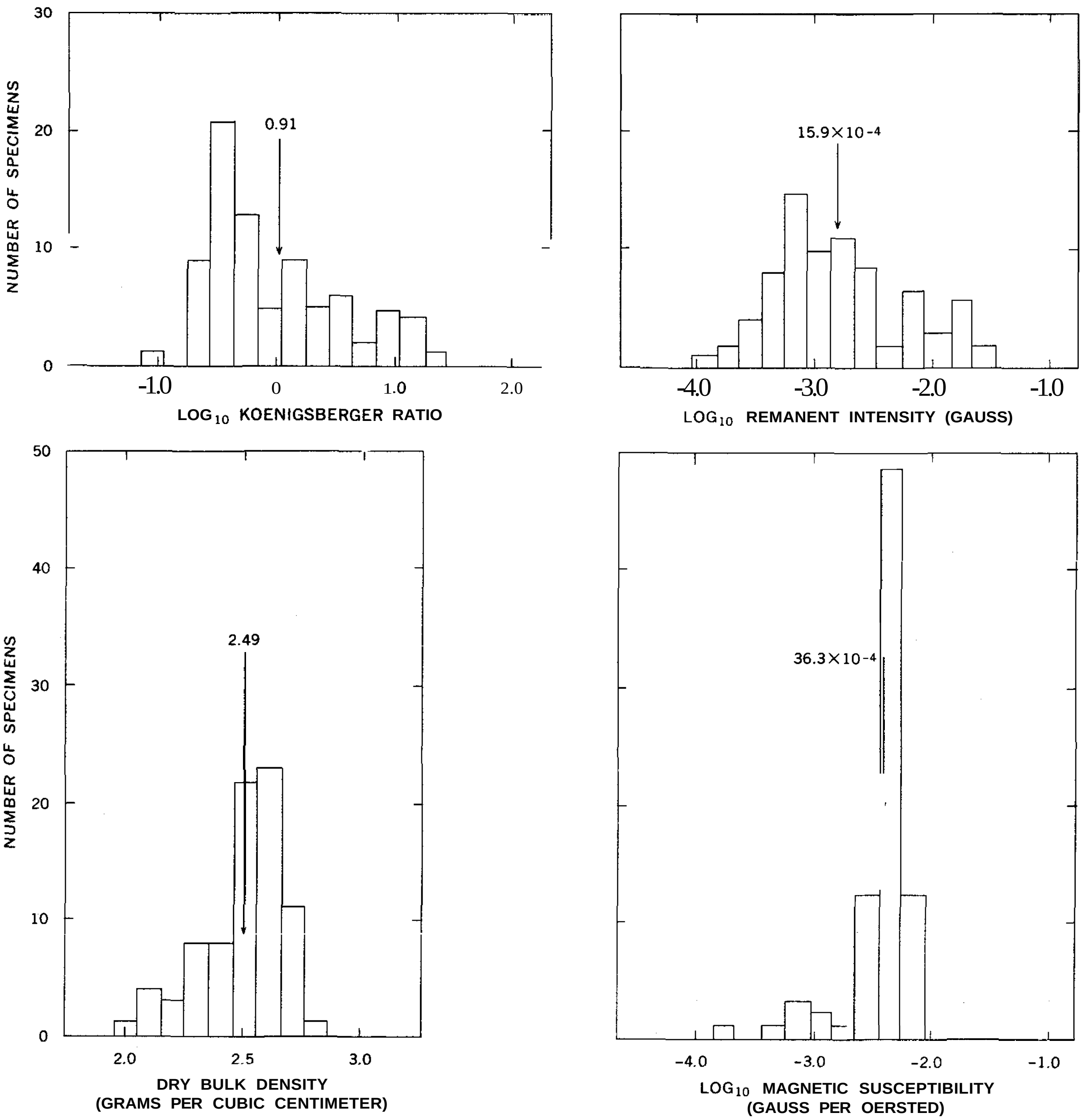

FIGURE 10. — Histograms of Koenigsberger ratio, density, remanent intensity, and magnetic susceptibility for 81 drill-core specimens of andesitic and basaltic flows, sills, and dikes. Arrow indicates average value.

mens collected from **26** samples at **11** sampling sites average 26.4×10^{-4} gauss per oersted for magnetic susceptibility and 15.1×10^{-4} gauss for remanent intensity. Average total magnetization, having a direction that approximates the present geomagnetic field, is 27.4×10^{-4} gauss.

A few strongly magnetized surface samples that the authors have collected to date show intermediate remanent polarities. For example, the **10** surface specimens of basalt collected from five samples at four sampling sites in the Banjo Point Formation average 29.1×10^{-4} gauss per oersted for magnetic susceptibility and 114.6×10^{-4} gauss for remanent intensity. The intermediate directional data for these samples are shown in figure **12.** The average total magnetization for these samples is 111.5×10^{-4} gauss, having a declination of **316"** and an inclination of $-26°$.

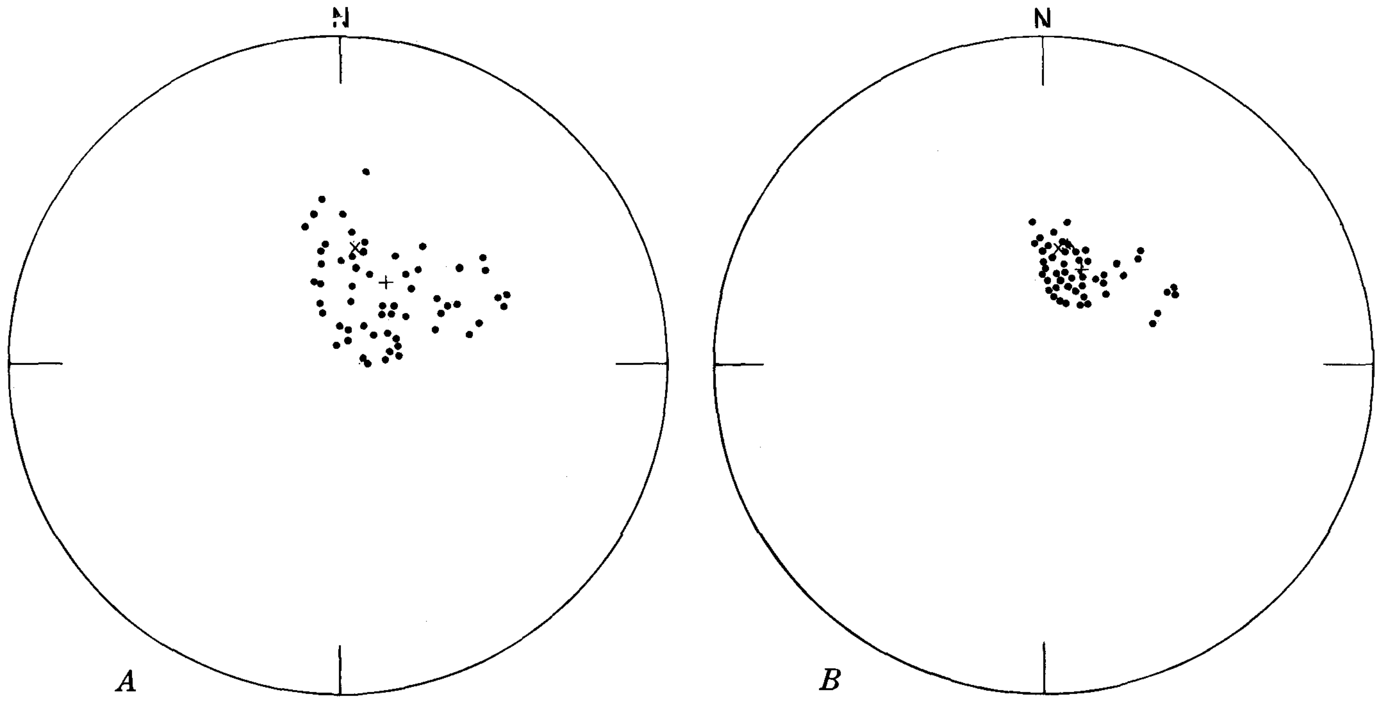

FIGURE 11. — Equal-area projections of remanent (A) and total (B) directions of magnetization for 58 specimens of andesitic lava collected from surface exposures of the Chitka Point Formation. ●, lower hemisphere; ×, present geomagnetic field; +, average direction.

AEROMAGNETIC ANOMALIES

The positions of several aeromagnetic anomalies having values well above the regional anomaly correlate with the positions of known exposures of relatively young andesite lava flows of the Chitka Point Formation. Bird Rock, Windy Island, and Site F positive anomalies are over these flows on the northwestern part of the island (pl. 2). The Infantry Road anomaly is over exposures that are mainly breccia, but flows probably lie beneath the breccia. The edge of the large positive feature named the Chitka Point–Constantine Point anomaly is also over the flows. It has been previously pointed out (p. 8) that the positive Site B anomaly and the negative Mex Island, **—780,** Rifle Range Point, and Pillow Point anomalies are at least partly related to older lavas that are buried within or beneath the Banjo Point Formation.

GROUND SURVEY ANOMALIES

The data obtained from the traverses and plotted on plate 3 show the characteristic irregular pattern of magnetic anomalies over lava. Weiss **(1949)** was perhaps the first investigator to point out the extreme variations in the ground anomalies beneath the aeromagnetic anomalies caused by near-surface and reversely magnetized rocks.

Data obtained from the short traverse along Clevenger Road illustrate the effects of strongly magnetized rock buried beneath nonmagnetic rock. The irregular and negative residual anomalies indicate rocks having strong remanent intensities and reverse polarities that are assumed to be the pillow lavas of Kirilof Point. The low values of standard error indicate near-surface rocks that are considered nonmagnetic, such as breccia or alluvium.

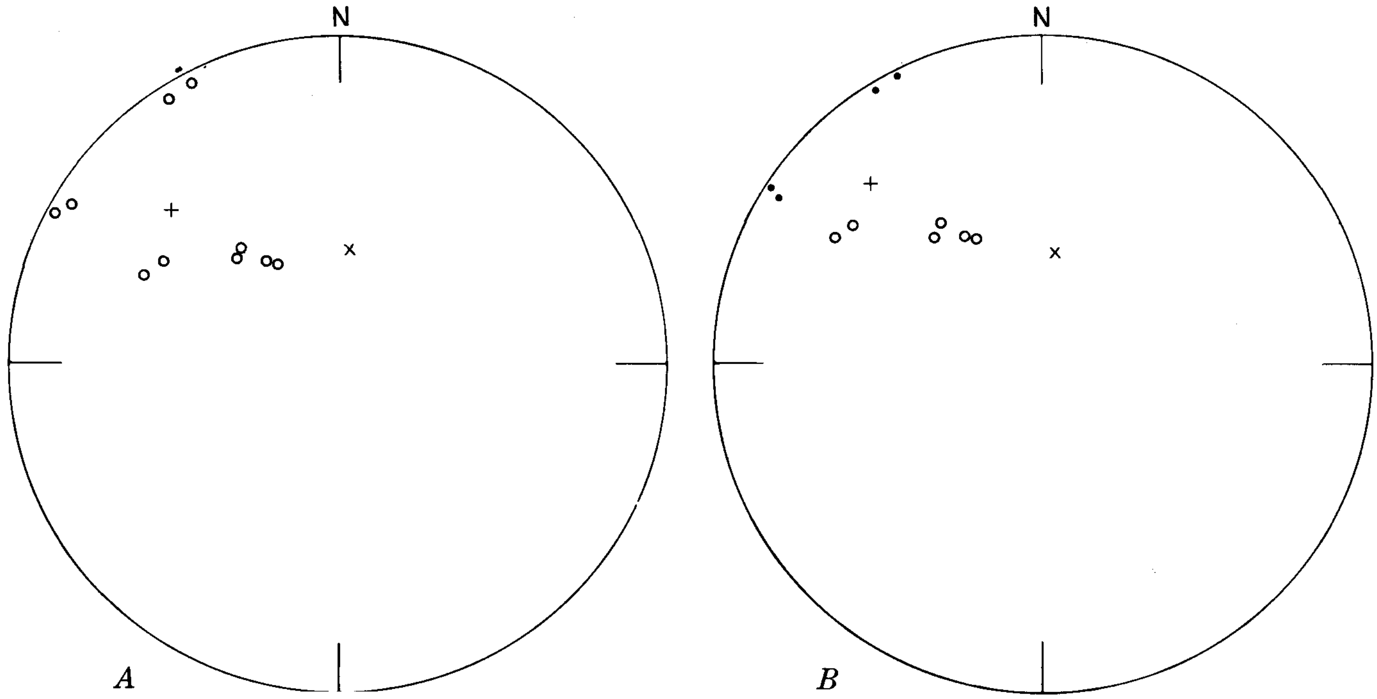

FIGURE 12. — Equal-area projections of remanent (A) and total (B) directions of magnetization for 10 specimens of basaltic lava collected from surface exposures of the Banjo Point Formation. ●, lower hemisphere; o, upper hemisphere; ×, present geomagnetic field; +, average direction.

ANALYSIS OF MAGNETIC ANOMALIES

A detailed investigation of the complex anomaly patterns given in the Amchitka aeromagnetic survey is possible in areas where individual anomalies stand out so clearly that they can be separated from neighboring magnetic effects. The understanding of geologic structure and magnetic properties of the rocks on the island enables one to identify many of the anomaly-producing features, compute estimates of depths to their tops, and make inference about their lateral extents and thicknesses.

The identification of anomaly-producing features becomes more difficult over the insular shelf where little is known about marine geology. However, considerations of magnetic properties and magnetic anomalies over the island units permit a qualitative analysis of many of the anomalies shown on plate 2. The most likely causes of complex anomaly patterns are the strongly magnetized lava flows and thick sills within the Amchitka and Banjo Point Formations; the positive anomalies being related to rocks which have positive inclinations of remanent direction, and the negative anomalies to rocks which have negative inclinations of remanent direction. Most of the broad positive anomalies with the more moderate anomaly patterns are undoubtedly produced by normally magnetized lava flows of the Chitka Point Formation. Areas of relatively uniform anomaly could overlie large volumes of either intrusive rock, sedimentary rock, or volcanic breccia.

DEPTH ESTIMATES

Several investigators working in petroleum-rich areas pointed out the advantage of using aeromagnetic data to obtain preliminary estimates of the thickness of the sedimentary section throughout extensive areas (Steenland, 1965; Henderson and Zietz, 1958). Their premise is that sedimentary rocks are nonmagnetic and any magnetic anomalies must originate from the underlying igneous rocks. Calculation of depth to the magnetic rock therefore yields a thickness estimate for the sedimentary rocks.

On Amchitka, the igneous rocks are at or very near the surface. Some rocks, such as volcanic breccia, are relatively nonmagnetic and do not significantly distort aeromagnetic anomalies arising from deeper, strongly magnetized rocks. These magnetic anomalies were analyzed to determine thicknesses of breccia, some lava flows, and other rocks having low magnetizations. Computed depths were compared with the actual depths of known geologic features that had been obtained by drilling.

In general, shallow sources give sharp anomalies having short wavelengths, and deep sources give broad anomalies having long wavelengths. Numerous simple rules have been introduced to determine depth or some other dimension of the anomaly source (Vacquier and others, 1951; Grant and West, 1965). Most rules are made in accordance with some property of an anomaly calculated for models of varying depth, length, width, thickness, magnetization, or geomagnetic latitude. Often the property consists of the horizontal distance between two critical points of the anomaly. For most Amchitka anomalies, computations were made for horizontal sheet and dipole models: first, the extent of maximum slope (Vacquier and others, 1951); second, the interval between the one-half maximum slope intersections with the anomaly curve (Peters, 1949); and third, the interval between inflection points (Bean, 1966). Comparison of these computed anomaly properties with similar properties of an actual anomaly will yield the depth estimate.

Figure 13 was prepared to illustrate observed data from magnetometer records, anomalies produced by near-surface rocks, and an anomaly produced by

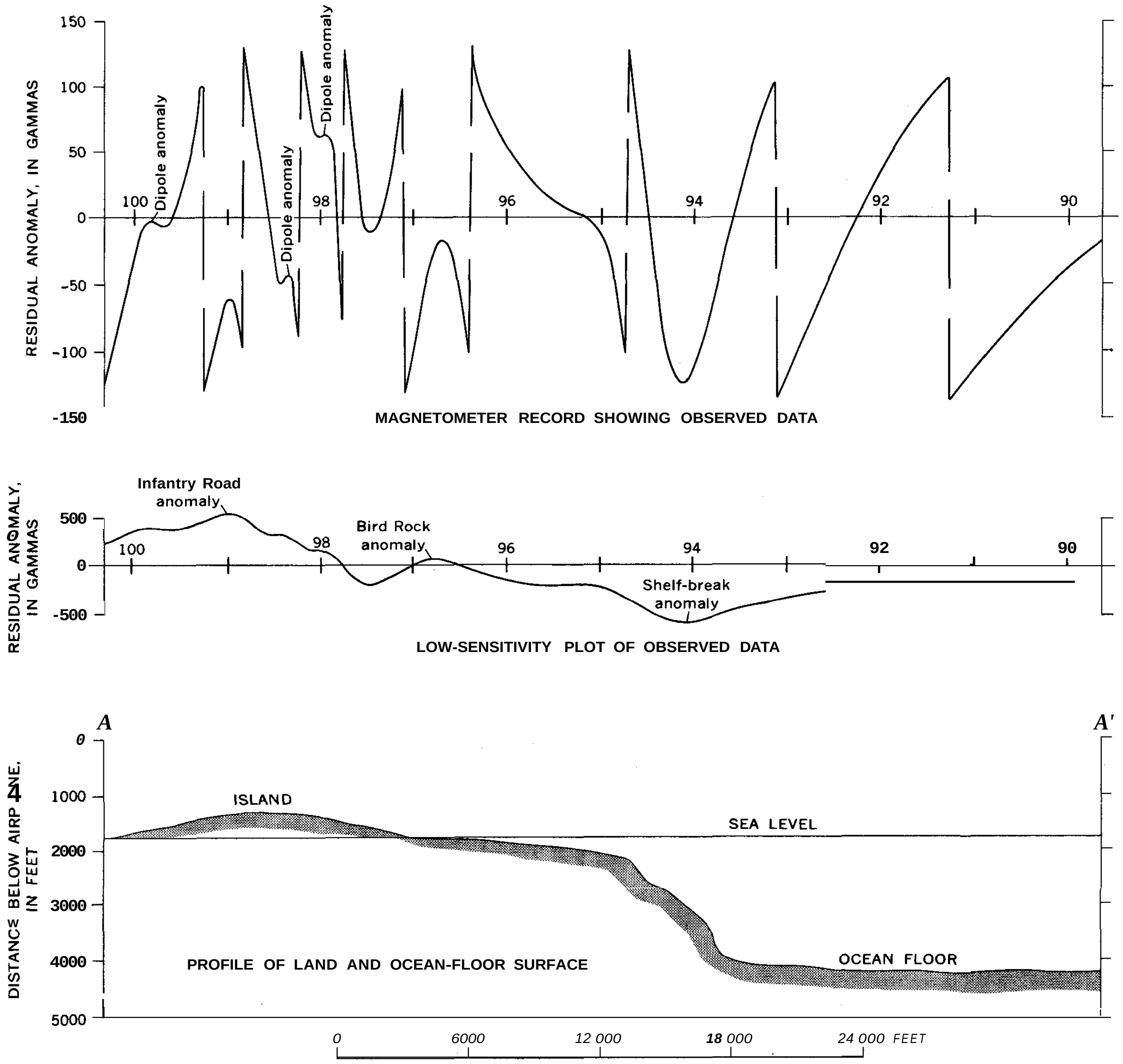

FIGURE 13. — Observed data from magnetometer record and from low-sensitivity plot superimposed on profile A–A' along flight line 111, as shown on plate 2.

rocks below sea level. The data were recorded at a scale of about 1:30,000, and the distance from airplane to ground and water surface was obtained by radio altimeter. Anomaly analysis indicates that the rocks causing the shelf-break anomaly are along the shelf break and 1,100 feet below sea level, those causing Bird Rock anomaly are at the ground surface, those causing the two dipole anomalies on the north side of Infantry Road anomaly are at the ground surface, and those causing the Infantry Road anomaly and the dipole anomaly on its south side are buried 500 feet beneath the ground surface.

DIPOLE AND SHEETLIKE MODELS

In spite of the complexity of the earth's magnetic field at a barometric elevation of 1,600 feet (pl. 1), certain individual anomalies do stand out (pl. 2), and they appear to represent the effect of single magnetized bodies. For these anomalies, a quantitative method of interpretation may give information on the length, width, and thickness of the magnetic feature. The method consists of finding the model, or models, that are both geologically reasonable and capable of causing an effect equivalent to the anomaly.

A sharp anomaly having an interval of only about one depth unit (or less) between maximum and minimum values was considered as a model of point dipole effect. One depth unit is equal to the distance from airplane to anomaly-producing rocks. Such a model represents a fairly small geologic feature that has roughly the same dimensions in all directions. Experimental examples of dipoles are the three small anomalies shown superimposed on the Infantry Road anomaly of figure 13, and theoretical examples are data on the five traverses shown in figure 14. The dipole anomaly portrays the limiting case that gives no information on the dimensions of the source. A strongly magnetized body that measures only a few feet on a side will produce the same anomaly configuration as a body with dimensions up to about half a depth unit. Larger dimensions will distort the anomaly and thus show a shape effect.

To investigate the dipole effect, anomalies for five directions of traverse over a dipole source were computed from $\frac{\Delta T t^3}{\mu}$ (eq 8 of Hall, 1959, p. 1947), as shown in figure 14. The depth from datum line to source is designated t, and traverse distance, x, is expressed in depth units. The direction of total magnetization is parallel to the earth's magnetic field at Amchitka, μ is the dipole moment, and ΔT is the anomalous total magnetic field measured by the airborne magnetometer.

Lava flows frequently occur as well-defined magnetic bodies that have dimensions nearly approaching those of a horizontal sheetlike model. The sheet model has practical importance also because its anomaly does not change in shape for the sake of increases in thickness up to about one depth unit. The anomaly pattern does change for increases in length (fig. 15*A*) and for increases in width (fig. 15*B*). Also, when the average total magnetization of the body is known, calculations based on the anomaly amplitude will give an estimate of thickness.

By using a thickness of one-third depth unit and then converting to the sheet notation, the anomalies of figure 15*A* were computed from equations 4.3a and 4.3b of Werner (1953, p. 17), and the anomalies of figure 15*B*, from the prismatic models of Vacquier, Steenland, Henderson, and Zietz (1951). The direction of total magnetization, J_t, is parallel to the earth's magnetic field at Amchitka, and the thickness of the sheet model, ε, is expressed in depth units, ε', where $\varepsilon'=\frac{\varepsilon}{t}$. The model length, l, width, w, and the traverse distance, x, are also expressed in units of depth, t.

INTERPRETATION OF ANOMALIES

The following discussion deals with some of the magnetic anomalies that can be explained by known geologic facts. Also discussed are some anomalies and anomaly patterns that are subject to more conjectural interpretations.

The lava flows and thick sills produce most of the anomalies in the aeromagnetic survey. The theoretical magnetic anomalies plotted in figure 15 show steeper gradients near the boundaries of models, which represent simplified configurations for flows or sills having horizontal attitudes. Most drill holes are located away from the strong anomalies that have dominant trends or are terminated abruptly. Termination may also be caused by erosion or other geologic processes, and the present authors have relied heavily on geologic evidence before designating a feature as fault related.

Remanent magnetization exerts the most marked influence on the total magnetization of flows and sills, and remanent direction thereby becomes a dominant factor in determining anomaly configurations. The Koenigsberger ratio averages 0.9 for all the measured andesite and basalt specimens, and the ratio increases for many anomaly-producing formations. For example, the 58 specimens from the Chitka Point lavas (fig. 11) have a ratio of 1.2, and 10 specimens of basalt (fig. 12) have a ratio of 14.0.

EAST CAPE ANOMALY

At East Cape, Pillow Point, and Ivakin Point, the diorite complex intrudes both the older breccia and the breccias and pillow lavas of Kirilof Point. Contact metamorphism has locally changed some of the wallrock to hornfels. Explanation of the broad negative anomaly in the area of East Cape is based on the very low remanent intensity of the diorite and the somewhat higher values of the intruded breccia. Eight specimens of diorite (table 1) have a low average total intensity of 6.6×10^{-4} gauss along the direction of the geomagnetic field, which is a value just under the ambient level for the island. Thirteen samples of breccia, dikes, and sills from the area mapped as older breccia and hornfels (pl. 2) have somewhat higher average values — 4.4×10^{-4} gauss for remanent intensity, and 10.0×10^{-4} gauss for induced intensity — but the contrast is probably insufficient to explain the anomaly. We therefore conclude that lava flows in the older breccia are strongly enough magnetized to cause the contrast. Examples are samples Q57–66 and Q12–67 (sample sites 12 and 11, pl. 2) which have high average remanent and induced intensities of 156×10^{-4} and 24.5×10^{-4} gauss. Drill hole UAe–2 at site B penetrated several thick bodies of mafic magnetic rock in this general part of the section. For example, a hornblende andesite sample, collected at a depth of 6,002 feet, has remanent and induced magnetizations of 14.0×10^{-4} and 20.9×10^{-4} gauss.

WHITE HOUSE COVE AND SHELF-BREAK ANOMALIES

Another prominent negative anomaly related to intrusive rock is at White House Cove directly over outcrops of diorite porphyry that intrude the Banjo Point Formation and probably the Chitka Point Formation. The anomaly curves across the island to the Bering Sea side of Amchitka where there is a small outcrop of diorite (Carr and Quinlivan, 1969).

To explain the negative anomalies, two possibilities that require relatively low values of magnetization were considered. The first assumes that the White House Cove intrusive has a total magnetization lower than that of the adjacent rocks. The limited sample

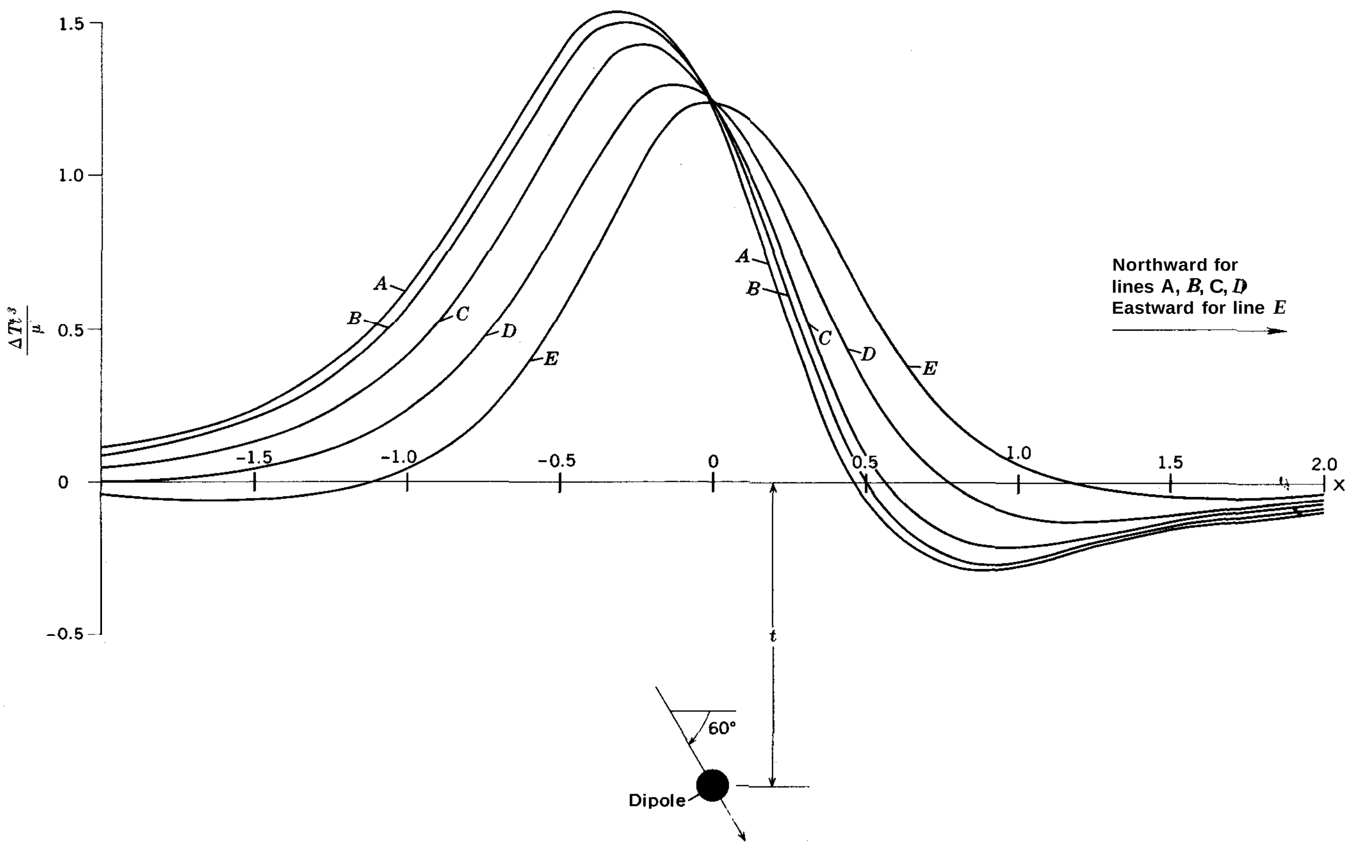

FIGURE 14. —**Theoretical magnetic anomalies, AT computed for five directions of traverse over a dipole source magnetized along the geomagnetic field having an inclination of 60". Strike of traverse lines: A, magnetic north; B, 22.5° east or west of magnetic north; C, 45° east or west of magnetic north; D, 67.5° east or west of magnetic north; E, magnetic east. *t*, depth from datum line to source; μ, dipole moment. x, traverse distance, is expressed in units of depth, t.**

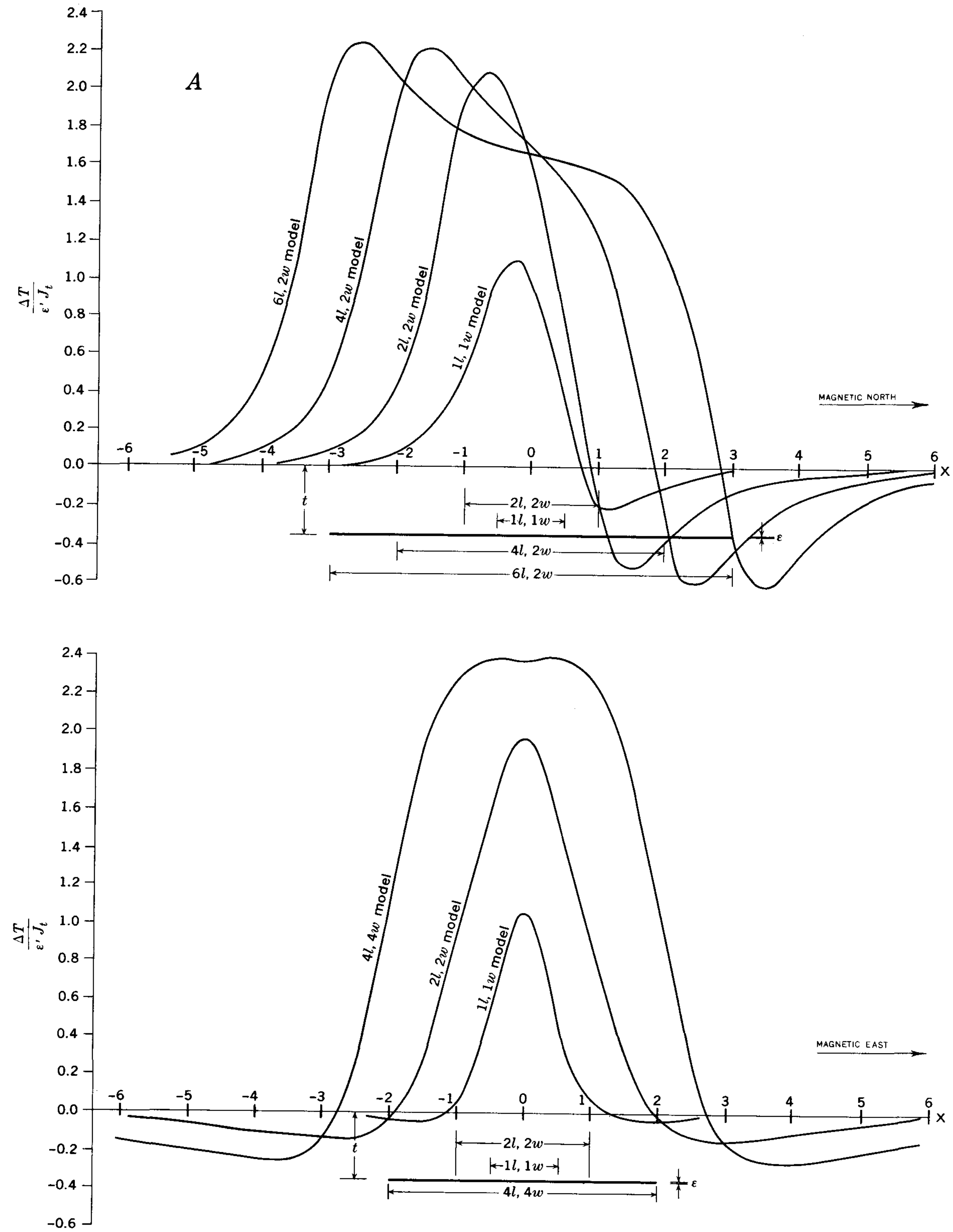

FIGURE 15. — Theoretical magnetic anomalies, AT, computed for the following: A, traverses striking magnetic north over the centers of four rectangular sheetlike models; B, traverses striking magnetic east over the centers of three square sheetlike models. All models magnetized along the geomagnetic field having an inclination of 60°. Model length, I, width, *w*, thickness, ε and traverse distance, X, are expressed in units of depth, t. $\varepsilon'=\varepsilon/t$; J_t, intensity of total magnetization.

data now available do not support this concept. According to table 1, the diorite has a total intensity which is well above the ambient level for the island and which is about equal to the total intensity of the Chitka Point lavas. This comparatively high value of magnetism would result in a positive rather than a negative anomaly relative to the Banjo Point and practically no anomaly relative to the Chitka Point.

The second possible explanation of the anomaly seems to be more reasonable. It requires a local decrease of magnetism in the near-surface volcanic rocks that overlie the pluton, and it requires a laccolithic structure that would give the pluton a thickness about equal to the total thickness of the Chitka Point lavas. A thicker intrusive could change the anomaly from negative to positive. The anomaly also extends over intensely altered lava flows of the Chitka Point Formation (pl. 2). This hydrothermally altered rock is represented by samples B4–67, B5–67, and Q30–67 (sample sites 4, 6, and 5, pl. 2), which have an extremely low total average magnetization of 0.5×10^{-4} gauss, a condition indicating the almost complete destruction of magnetite. Lava and breccia samples collected beneath the anomaly but outside the intensely altered zone such as samples B19–67, C75–67, and C76–67 (sample sites 3, 2, and 1, pl. 2) have an average total magnetization of 5×10^{-4} gauss, which is also well below the regional level. Much of this area shows evidence of weak to strong propylitic alteration, the chief minerals of which are pyrite, chlorite, and quartz.

Plate 1 shows that the White House Cove anomaly is only part of a much bigger negative anomaly that extends from the Bering Sea coast of Amchitka northwestward more than 25 miles, culminating in a very pronounced negative anomaly over the eastern part of Rat Island. The part north of the northwestern tip of Amchitka is designated as the shelf-break anomaly on plate 2. Its termination may be related to faulting along the shelf break, the escarpment that parallels Rat Island and Amchitka Island on the north. On Rat Island, the anomaly is over diorite porphyry that appears to be identical with the diorite on Amchitka. Alteration is also locally intense on this part of Rat Island. The total pattern of the anomaly thus subtends an elongated partial oval inside of which are lavas and probably source vents for the Chitka Point andesite lava flows. Gravity data (Miller and others, 1969) show that the western end of Amchitka is a gravity low. In addition, the fact that remanent directions shown in figures 10 and 11 are very similar for the White House Cove intrusive and the surrounding Chitka Point lava flows indicates that these rocks may be nearly contemporaneous. The two rocks — intrusive and lava — are also similar petrographically. All these data, though sketchy, suggest that the western end of Amchitka and the eastern end of Rat Island may constitute a large volcanic center related to the Chitka Point Formation and that the diorite porphyry may be a series of large ring dikes related to the volcanic center.

PILLOW POINT AND RIFLE RANGE POINT ANOMALIES

Analysis of the negative anomalies that trend southeastward from Pillow Point (pl. 2) indicates source rocks that are (1) near surface, (2) magnetized in a negative or upward direction, and (3) elongated in the direction of strike. The anomaly is less than 2,000 feet wide but extends southeast from the island 6 miles. At the shoreline of Amchitka the anomaly correlates with pillow lavas of Kirilof Point as mapped by Carr and Quinlivan (1969). The anomaly is also over intrusive rocks at Pillow Point. Although intrusive rock samples C83–66 and Q79–66 (sample sites 10 and 9, pl. 2) were not oriented to determine remanent direction, other data show that they do not have the required total magnetization and have a negative or upward direction. Their average induced intensity (20.1×10^{-4} gauss) is greater than the remanent intensity (17.8×10^{-4} gauss), and this will result in a total magnetization having a downward direction. The pillow lavas of Kirilof Point, however, are known to have upward total direction, and these rocks crop out beneath the anomaly and have a strike that is nearly the same as the anomaly.

Part of the Rifle Range Point anomaly (pl. 2) correlates fairly well with those pillow lavas of the Kirilof Point that are presumed responsible for the Pillow Point anomaly. However, the anomaly diverges from outcrops of the pillow lavas and appears to follow the southeast side of the Rifle Range fault out into the Pacific. The rocks that cause this part of the anomaly have not been identified, but a possible explanation is given in the following discussion of the St. Makarius Point anomaly.

ST. MAKARIUS POINT ANOMALY

The downward inclination of the total magnetization of the five samples collected from dikes and sills beneath the St. Makarius Point negative anomaly (pl. 2) shows that these are not source rocks. Depth estimates support this interpretation. The depth estimated from the negative anomaly on profile T–16 (pl. 1) is at least 500 feet below the surface. The anomaly is near the axis of a gentle northeast-trending syncline. This fold may be a result of uplift due to intrusion of the diorite to the east. It seems reasonable to assume that the St. Makarius Point anomaly is caused by reversely magnetized but locally thicker pillow lavas near the top of the Kirilof Point rocks. These would lie between 1,000 and 1,500 feet below the surface at the location of the anomaly. The apparent thickening of this reversely magnetized lava in a structural depression further suggests that this depression was present in late Kirilof Point time. This means that structural movements may have begun in Kirilof Point time. Support for this concept is also found in the previously mentioned Rifle Range Point anomaly in which the buried source rocks of the strongest negative anomalies are removed from the trend of the present strike of these lavas. Here, too, the only rocks known to be capable of causing the anomaly are pillow lavas of Kirilof Point. These may be thicker and structurally localized in the Rifle Range Point area, just as they are thought to be in the St. Makarius Point area. Furthermore, the largest and most intense negative anomalies on or near Amchitka lie offshore (pl. 1), south and west of the Rifle Range Point anomaly where one string of negative anomalies projects seaward. This culminates in a large negative anomaly about 4 miles southwest of Rifle Range Point.

MEX ISLAND ANOMALY

This negative anomaly appears to be another that is attributable to the pillow lavas of Kirilof Point. Like the anomalies at Rifle Range and St. Makarius Points, it occupies a position on the upthrown side of a major fault. Although the Kirilof Point does not crop out in this area, pillow lavas of the Kirilof Point were found in drill hole UAe–1 at a depth of about 1,400 feet. The depth estimated from the anomalies on profiles T–130 and T–8 (pl. 1) is 1,300 feet to the top of the source rocks. A considerable part of the section penetrated between 1,400 and 6,100 feet in UAe–1 is reversely magnetized, although at most depths the remanence is weak. Like the Rifle Range Point anomaly, the Mex Island anomaly extends seaward several miles to a large pronounced low over the ocean floor (pl. 2).

BIRD ROCK, WINDY ISLAND. CHITKA POINT-CONSTANTINE POINT ANOMALIES

The Chitka Point andesite lava flows are normally magnetized, and, where relatively thick or high in total intensity, they produce positive anomalies. Examples are the Bird Rock, Windy Island, and Chitka Point–Constantine Point anomalies (pl. 2). Almost all oriented samples collected beneath these anomalies have positive remanent inclinations. The one notable exception which has a high negative inclination value, sample B7–67 (sample site 7, pl. 2), was collected from a feature that is probably too small to give an aeromagnetic anomaly.

The Windy Island anomaly corresponds to a pile of fairly young subaerial andesite lava flows that make up the highest part of Amchitka. These flows dip seaward from the high points of the island, and the aeromagnetic data suggest that they extend well out into the ocean, particularly south of Windy Island. As previously described, the White House Cove anomaly, a result of alteration associated with intrusion, appears to cut across the anomaly produced by the less altered lavas of the Chitka Point Formation.

The Chitka Point–Constantine Point anomaly is mostly over water, but at the northwestern end it is over lava flows of the Chitka Point Formation. It seems reasonable to assume that these lavas, which appear to dip seaward, thicken or are less altered northeast of Amchitka in the area of the anomaly. It is also possible that the southeastern part of the anomaly is due to basaltic rocks in the Banjo Point Formation.

The Infantry Road anomaly, also over the Chitka Point Formation, is mostly over altered andesitic breccias that are not highly magnetic. The anomaly may result from andesite lava flows buried beneath the breccias. Andesite is reported at a depth of about 80 feet in a drill hole in the eastern part of this area.

SITE B ANOMALY

This anomaly, just north and on the downthrown side of the Rifle Range fault, is one of several positive anomalies over faultblock wedges of the Banjo Point Formation. Another unnamed anomaly lies in a similar position north of the major fault between St. Makarius Bay and Constantine Harbor.

−780 ANOMALY

This negative anomaly appears to be produced by a reversely magnetized near-surface lava flow or sill in the Banjo Point Formation. The body is represented by sample C24–67 (sample site 8, pl. 2). It has a magnetic susceptibility of 35.5×10^{-4} gauss per oersted, a remanent intensity of 37.5×10^{-4} gauss, a remanent declination of 210°, and a remanent inclination of −57°.

SITE F ANOMALY

The anomalies discussed so far stand out clearly from those in neighboring areas, and they are reflected by data taken on several aeromagnetic traverses. The Site F anomaly is one of the numerous small anomalies that relate to only one or two traverses. The anomaly has an amplitude of 150 gammas in the aeromagnetic survey (pl. **2)** and 500 gammas in the ground magnetic survey (pl. 3).

A depth estimate from profile T–123 (pl. 1) places the anomaly-producing rocks at about 100 feet below the ground surface. Drill hole UAe–3, which started in breccia, penetrated Chitka Point andesite at a depth of 180 feet (Lee, 1969). Four drill-core specimens of the lava average 36.0×10^{-4} gauss per oersted for magnetic susceptibility, 3.9×10^{-4} gauss for remanent intensity, and 68" for remanent inclination. If we assume a northward declination, the average total magnetization becomes 21.2×10^{-4} gauss for intensity, 6" for declination, and 64" for inclination.

RELATION OF SUBMARINE STRUCTURE SOUTH OF AMCHITKA TO AEROMAGNETIC ANOMALIES

A comparison of plate **1** with the generalized geologic map (pl. 2) showing possible submarine faults beneath the Pacific Ocean indicates that landward projections of the pronounced submarine canyons, on which the existence of these faults is inferred, do not show a consistent relationship with aeromagnetic contours. Many of the hypothetical faults cross the aeromagnetic contours at fairly large angles. There is a suggestion of local parallelism between aeromagnetic contours and inferred submarine faults above the submarine terrace at about 325 feet below sea level. But most faults on **Am**chitka, such as the pronounced Rifle Range fault (pl. 2), apparently either die out seaward or are overlapped by anomaly-p oducing rocks. Carr and Quinlivan **(1969)** inferred from submarine contours a northeast-trending fault through South Bight which would have to cross the Pillow Point anomaly and not produce any marked effect on the aeromagnetic pattern. South of Amchitka, the erratic distribution of anomalies with respect to submarine topography (pl. **2)** might be explained by an intersecting fault system, by interruption of faults by intrusive masses, or by a combination of both.

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U. S. GOVERNMENT PRINTING OFFICE : 1972 O - 456-237